# A - Inquiring and analysing

Wednesday, 27 January 2021 7:38 PM

The student:

I. **explains** and **justifies** the need for a solution to a problem for a client/ target audience
II. **constructs** a **detailed** research plan, which **identifies** and **prioritizes** the primary and secondary research needed to **develop** a solution to the problem independently
III. **analyses a range of** existing products that inspire a solution to the problem in detail
**develops** a **detailed** design brief, which **summarizes** the analysis of relevant research.

☐ Identified a suitable client/target audience
☐ **Explained** and **justified** the need for bone scaffolds
☐ **Constructed** a **detailed** research plan to **identifies** and **prioritizes** the primary and secondary research needed to develop an appropriate process that includes:
  - 3D printing
  - Properties of bone scaffold
  - Scientific testing
  - Forces
☐ **Analysed** a range of processes and/or bone scaffolds

**Developed** a **detailed** design brief which **summarizes** the analysis of the research.

# A (i) Explain and Justify the need for solution to a problem for a target audience

Wednesday, 27 January 2021 7:48 PM

A(i) **explains** and **justifies** the need for a solution to a problem for a client/ target audience

**Format: 400-500 words in sentences**

The consumer of the bone scaffold will be children under the age of 12 with segmental tibial fractures. Segmental fractures are caused by high energy mechanism and devascularisation of the segmental fracture fragments (Lujikx, Skalski, 2020). This fracture (figure A) is more common amongst children because their bones, especially the tibia, are undergoing development, possess bones that are much softer and more vulnerable than adult bones, and participate in more active practices than adults (HHS, 2010). Segmental tibial fractures account for 12.8% of tibial fractures; and an estimated 50% of them are open. Segmental fractures have a complication rate of 70.2% (East and Central African Journal of Surgery, 2007) because of the fragility and vulnerability of the bones and surrounding tissues before, during and after surgical intervention.

In most cases, a temporary titanium rod (Hutmacher, 2021) will be inserted into the bone with multiple nails securing its position (figure B and C). In another operation once the fracture is healed, the rod will be removed. Though these rods are mechanically advantaged and secure, they are difficult to customise to anatomically suit the patient and are not porous or elastic. Especially, for children under 12, this option is not suitable because instalment of foreign materials into bones may affect their bone development and cause permanent damage.

A survey distributed to a relative's colleagues (Pham, 2021), who were independent adults with varied occupations and fields of expertise, presented results as follows: 54.55% of participants (Figure D) knew a friend, family or relative under 12 years of age with a bone fracture; within that group 81.82% of respondents (Figure E) had never heard of the term regenerative medicine; and 72.3% did not consider or use a bone scaffold to mend the fracture. These results suggest consumer's parents or guardians are often not aware of less intrusive alternative options, including bone scaffolds, and choose to let their child undergo the more reliable but outdated and unsafe method.

Regenerative medicine is a new and controversial cutting-edge industry therefore the influence of this industry's findings and its proposals are not valued or applied universally. Controversy and insufficient coverage in the media are reasons why decision makers will not consider this option.

Modern bone scaffolds are composed of mechanically strong elastic biodegradable polymer (Hutmacher, 2021), use biologically inspired structures to aid in natural bone regeneration (Hutmacher 2021), and their designs can be customised anatomically precise to the patient's body using 3D printing technology (Hutmacher, 2021; Khatami, 2020). This innovation eliminates concerns of using the 'metal rod' method: the inelasticity, the lack of porosity, the intrusion to the body, and the difficulty to customise.

Therefore, clients, who are the end consumer's parents or guardians, being unconscious of safer, less intrusive and lower complication rated methods are a problem.

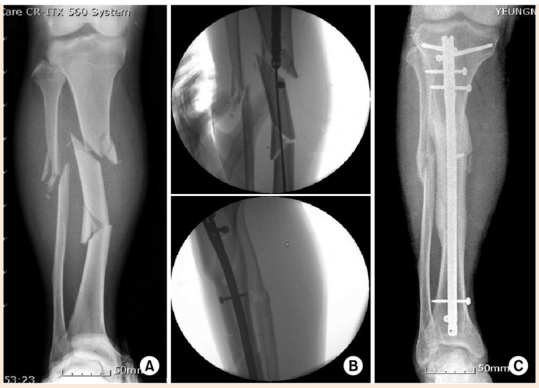
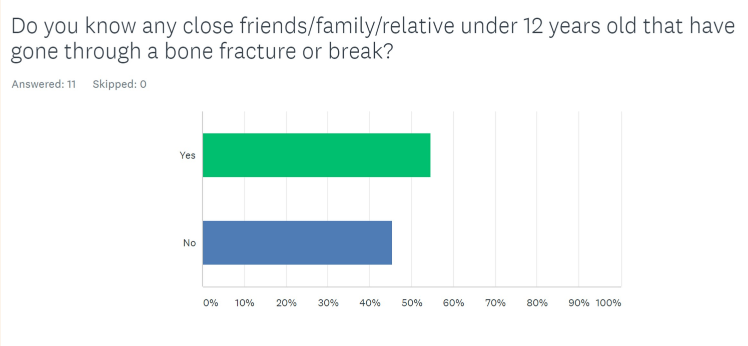
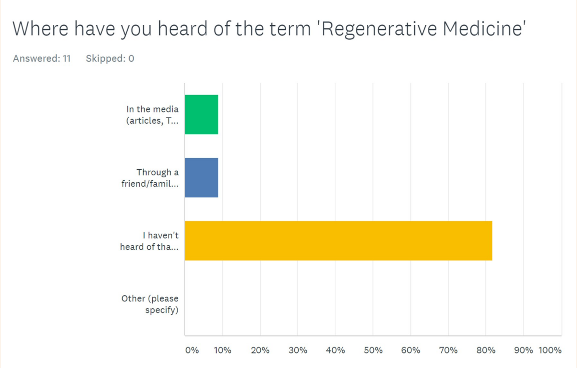


Figure A: top view of segmental tibial fracture
Figure B: side views of fracture after implant
Figure C: top view of tibia after implant


Do you know any close friends/family/relative under 12 years old that have gone through a bone fracture or break?

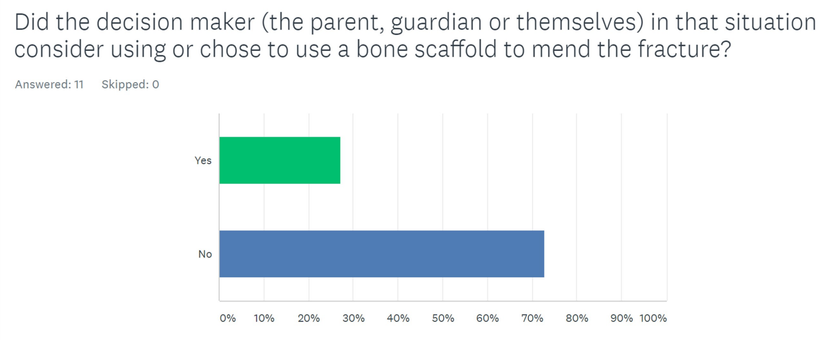
Answered: 11 Skipped: 0

Figure D: local survey results of "do you know any close friends/family/relative under 12 years old that have gone through a bone fracture or break?"


Where have you heard of the term 'Regenerative Medicine'

Answered: 11 Skipped: 0

Figure E: local survey results of "Where have you heard of the term 'Regenerative Medicine'?"


Did the decision maker (the parent, guardian or themselves) in that situation consider using or chose to use a bone scaffold to mend the fracture?

Answered: 11 Skipped: 0

Figure F: local survey results of "Did the decision maker in that situation consider using or chose to use a bone scaffold to mend the fracture?

*Word Count :*

# A (ii) Research Plan

Wednesday, 27 January 2021 8:08 PM

**A (ii) Constructed** a **detailed** research plan, which **identifies** and **prioritizes** the primary and secondary research needed to **develop** a solution to the problem independently

**FORMAT: Table in bullet points. No more than one A4 in size.**

| **Criterion A(ii) Research Plan** | | | | |
|---|---|---|---|---|
| Research Question(s) | Data to be collected and type | Sources (Primary and/or secondary) How will I gather the information? | Date | Priority (Essential or desirable) |
| 1: What are properties of bone scaffolds? | Notes;<br>Primary & secondary;<br>qualitative | primary | 8/2/21 | essential |
| 2: How do bones regenerate? | Notes;<br>secondary; qualitative, quantitative | secondary | 21/2/21 | essential |
| 3: What material is most suitable for this bone scaffold? | Notes;<br>Secondary, qualitative | primary | 8/2/21 | essential |
| 4: How will I test my bone scaffold? | Notes;<br>Primary, Quantative | primary | 18/2/21 | essential |
| 5: What is Young's Modulus? | Notes; Primary; qualitative | primary | 9/2/21 | essential |
| 6: How will I present my idea? | Notes; Primary; qualitative | secondary | 19/2/21 | essential |
| 7: How will I make a bone scaffold from a 3D printer? | Notes; Primary; qualitative | primary | 9/2/21 | essential |
| 8: Why are 3d printers most suitable for making bone scaffolds? | Notes; secondary; qualitative | secondary | 9/2/21 | desirable |
| 9: Who is the consumer? | Notes; Primary; qualitative; quantitative | Primary, secondary | 9/2/21 | essential |
| 10: How can I give my bone scaffold a mechanical advantage? | Notes; secondary; qualitative | secondary | 9/2/21 | desirable |
| 11: How will my design process be recorded? | Notes; secondary; qualitative | primary | 9/2/21 | desirable |
| 12: What are the key words in this unit and what do they mean? | Notes; secondary; qualitative | secondary | 8/2/21 | essential |

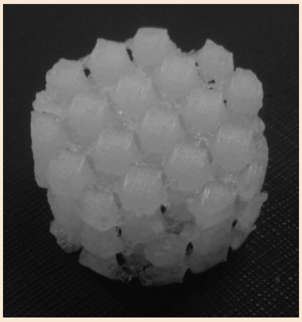
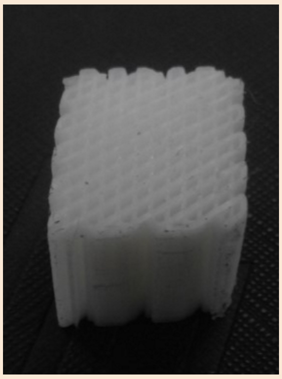
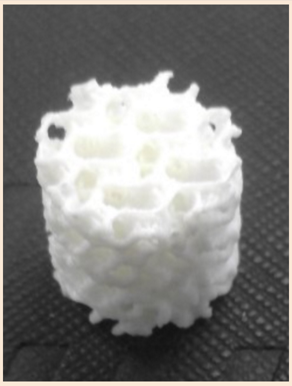
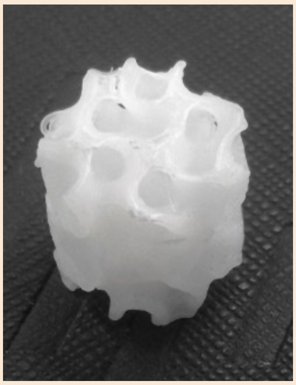
# A (iii) Analysing Existing Products

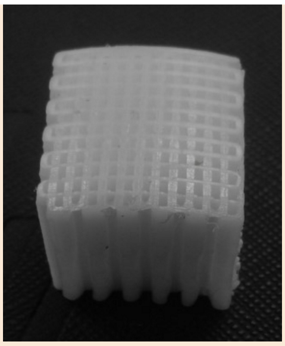
Monday, 1 February 2021 11:41 AM

**A (iii) analyses a range of** existing products that inspire a solution to the problem in detail

**FORMAT:**

- Table
- Brief bullet points
- No more than ONE A4 page

| **Criterion A(iii) Product Analysis** | Brief description | Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|---|---|
|  | Composed of cubes in grid organisation connected by spiderweb-like strings | • Elastic<br>• Mechanical advantaged shape<br>• Porous<br>• Flexible<br>• Good compressive resistance - cubes pack on top of each other<br>• permeable | • Connections between the cubes are weak | • "strings" connecting the cubes can be thicker to make the scaffold less fragile | • Tensile strength - being pulled will break the "string" bonds<br>• Inside of a body, the "strings" will biodegrade and leave only cubes<br>• Compression would put stress on regenerating cells in between cubes |
|  | 30, 60 zig-zag patterned cube with walls | • mechanically strong<br>• dense<br>• Solid<br>• Rigid<br>• sturdy | • solid walls do not allow cells to enter<br>• Small pores<br>• Parallel vertical pores that do not intersect<br>• Not elastic<br>• Bad material - too solid<br>• Too dense<br>• Corners too sharp for cells | • remove walls so cells can come through horizontally<br>• Larger pore size | • hazard to body - take too long to biodegrade<br>• Weaker if force applied from side (walled side) |
|  | Gyroid patterned cylinder | • organic shape<br>• Mechanical advantaged shape | • not elastic<br>• Small pores<br>• Brittle<br>• Bad material - too solid | • Higher quality print | • Hazard to body - biodegrades too quickly |
|  | Gyroid patterned cylinder | • large enough pores<br>• Organic shape<br>• Mechanical advantaged shape<br>• High quality print<br>• Somewhat elastic<br>• Elastic<br>• Flexible<br>• Good compressive potential | • non linear randomised pattern - difficult for cells to navigate | • replace random-like generated pore tunnels with gridded orderly structure | • when compressed, would retract too much - cause too much displacement and damage to nearby tissues and regenerating cells |

| | | | | | |
|---|---|---|---|---|---|
|  | Walled zig zag gridded cube | • mechanically strong<br>• dense<br>• Solid<br>• Rigid<br>• sturdy<br>• | • solid walls do not allow cells to enter<br>• Small pores<br>• Parallel vertical pores that do not intersect<br>• Not elastic<br>• Too dense<br>• Bad material - too solid<br>• Corners too sharp for cells | • remove walls so cells can come through horizontally<br>• Larger pore siz | • hazard to body - take too long to biodegrade<br>• Weaker if force applied from side (walled side)<br>• |

# A (iv) Detailed design brief

Monday, 1 February 2021 11:43 AM

**A (iv) develops** a **detailed** design brief, which **summarizes** the analysis of relevant research.

**Criterion A(iv) Design Brief**

1. Who is the audience and what is their problem/needs?

- The audience is decision makers of children under 12 with segmental tibial fractures
- The decision makers need to make the safest, cheapest and most reliable method for their child under 12 years of age with segmental tibial fractures using the information and resources they have access to and are provided
- The problem is the deficiency of information of alternative methods such as biodegradable less intrusive bone scaffolds provided to decision makers (refer to Appendix A)
- The lack of information is evident in a survey conducted targeting adults who were or knew decision makers of children under 12 with bone fractures (refer to 9: Who is the consumer?)
- These survey results are representative of that a vast majority of people are unaware or misinformed on regenerative medicine.
- They need to know about this alternate method because segmental fractures are the most complicated and risky fractures to mend with a complication rate of 70.2% (refer to 9: Who is the consumer?)

2. How are you going to solve their need?

- Through informing the audience by creating a pamphlet that will be placed on pamphlet walls in waiting rooms of radiology clinics and children's wards in hospitals (refer to 6: How will I present my idea?)
- These pamphlets will be targeted towards decision makers of children with fractured bones
- Experiments proving the legitimacy of the previous claims (refer to Question 6)

3. How will your bone scaffold be made?

- The bone scaffold will be designed using Ultimaker Cura V4.8.0 and printed using 3d printer Prusa i3 Mk3 (refer to 7: How will I make a bone scaffold from a 3D printer?)
- 3d printers are most suitable for producing bone scaffolds because of their customisability, precision, flexibility, and range (refer to 8: Why are 3d printers most suitable for making bone scaffolds?)

4. How will your bone scaffold be tested?

- The focus of the experiments will be compressive/mechanical strength because bone scaffolds need to be able to endure the rigorous physical activity of children. (refer to 9: Who is the consumer?)

- The experiment will challenge how changing the porosity can affect the maximum force measured in Newtons, which will applied on the top cross section of the bone scaffold , can the bone scaffold absorb until break. (refer to 5: What is Young's Modulus?)

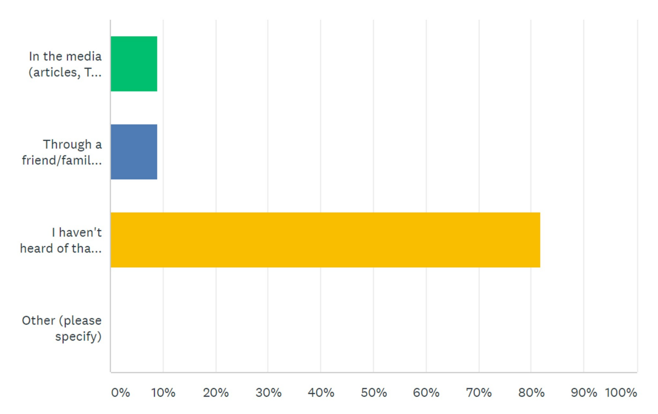
5. Are there any constraints to your tests?

- The equipment and resources available for the experiment are limited to the printers provided at school, the applications provided and household items
- Changing the porosity of the bone scaffold can consequently affect the pore size
- The experiment must be prepared and conducted within 30 minutes to keep the environment and conditions as indifferent as possible
- The environment and conditions that each trial will be executed will constantly change

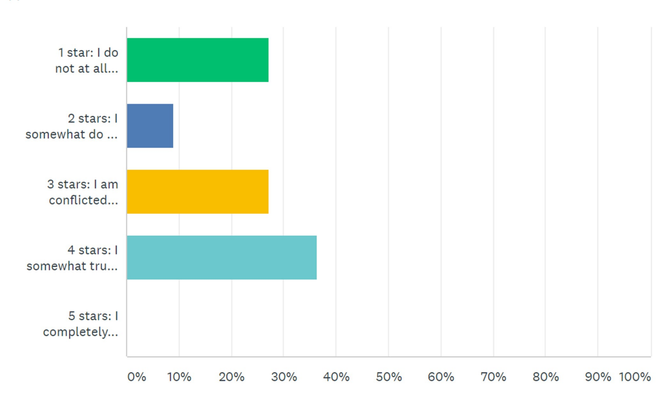
6. How will you evaluate the effectiveness of your bone scaffolds and their tests?

- The tests can prove how much compressive pressure can be applied to the bone scaffold despite the scaffold being porous and light (refer to 1: What are properties of bone scaffolds?)
- The effectiveness and advantage bone scaffolds have over traditional titanium "rods" is biology, weight and mechanical strength. (refer to 3: What material is most suitable for this bone scaffold?)
- If the bone scaffold exceeds a set mechanical strength while remaining under a certain weight, it is effective.

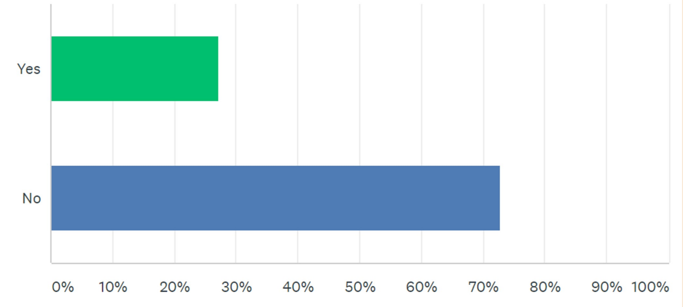
Appendix:



Appendix A: Local public responses to "Where have you heard the term 'Regenerative Medicine'?"



Appendix B: Local public responses to "Based on what you currently know about the field, what is your opinion on regenerative medicine and bone scaffolds?"



Appendix C: Local public responses to "Did the decision maker (the parent, guardian or themselves) in that situation consider using or chose to use a bone scaffold to mend the fracture?"

***Word count: 549 (excluding appendix)***

# B –Developing Ideas

Friday, March 12, 2021 11:12 AM

| **Criteria** | **B –** Developing ideas |
|---|---|
| **7 – 8** | The student:<br>**(i) develops detailed** design specifications, which **explain** the success criteria for the design of a solution based on the analysis of the research<br>I have developed detailed design specification that explain the success criteria based on my research<br>**(ii) develops a range of** feasible design ideas, using an appropriate medium(s) **and detailed** annotation, which can be **correctly** interpreted by other<br>I have developed a range of annotated diagrams showing methods which can be correctly interpreted by others<br>**(iii) presents** the chosen design and **justifies fully and critically** its selection with **detailed** reference to the design specification<br>I have presented the chosen method(s) and justified fully and critically with detailed reference to the design specification<br>**(iv) develops accurate and detailed** planning drawings/diagrams and **outlines** requirements for the creatin of the chosen solution.<br>I have developed accurate and detailed planning diagrams and outlined requirements for the creation of the method(s). |

# B(i) Design Specification

Friday, March 12, 2021 11:13 AM

| **Criteria** | **B –** Developing ideas |
|---|---|
| **7 – 8** | The student:<br>i. **develops detailed** design specifications, which **explain** the success criteria for the design of a solution based on the analysis of the research<br>ii. **develops a range of** feasible design ideas, using an appropriate medium(s) **and detailed** annotation, which can be **correctly** interpreted by others<br>iii. **presents** the chosen design and **justifies fully and critically** its selection with **detailed** reference to the design specification<br>iv. **develops accurate and detailed** planning drawings/diagrams and **outlines** requirements for the creation of the chosen solution. |

| **My audience is:** |
|---|
| Decision makers of children under 12 with segmental tibial fractures |
| **Scientific Aim:** |
| The experiment will challenge how changing the porosity can affect the maximum force measured in Newtons, which will applied on the top cross section of the bone scaffold , can the bone scaffold absorb until break. The hypothesis is: a 2cmx2cmx2cm bone scaffold cube will be able to withstand 9.81N of force applied to it. |
| **Why do I want my audience to know this?** |
| If the experiment proves the hypothesis correct, the bone scaffold can be justified to be a better alternative to traditional methods. Should the audience be aware of this field, they can make an informed decision on what treatment for their child to undergo. |

| **Success Criterion** | **Specific** | **Measurable** | **Attainable** | **Realistic** | **Timely** |
|---|---|---|---|---|---|
| The experiment must test the compressive strength of the bone scaffold | 🟩 | 🟧 | 🟩 | 🟩 | 🟧 |
| The experiment must be conducted on a level stable tiled floor | 🟩 | 🟧 | 🟩 | 🟩 | 🟧 |
| The experiment must be conducted in a low airflow $4m^2$ room (no openings over 50cm square) with temperature between 20℃ to 25℃ | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |
| Experiment can be assembled and conducted in $1 \leq 30$ minutes | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |
| The materials in the experiment must be household items with household-related primary purposes | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |
| The trials must be recorded with a minimum 60fps camera in slow motion | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |
| The sole variable changed in the experiment must be porosity | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |
| All scaffolds must be printed using same printer | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |
| The force applied to the bone scaffold in the experiment must be consistent | 🟩 | 🟩 | 🟩 | 🟩 | 🟧 |

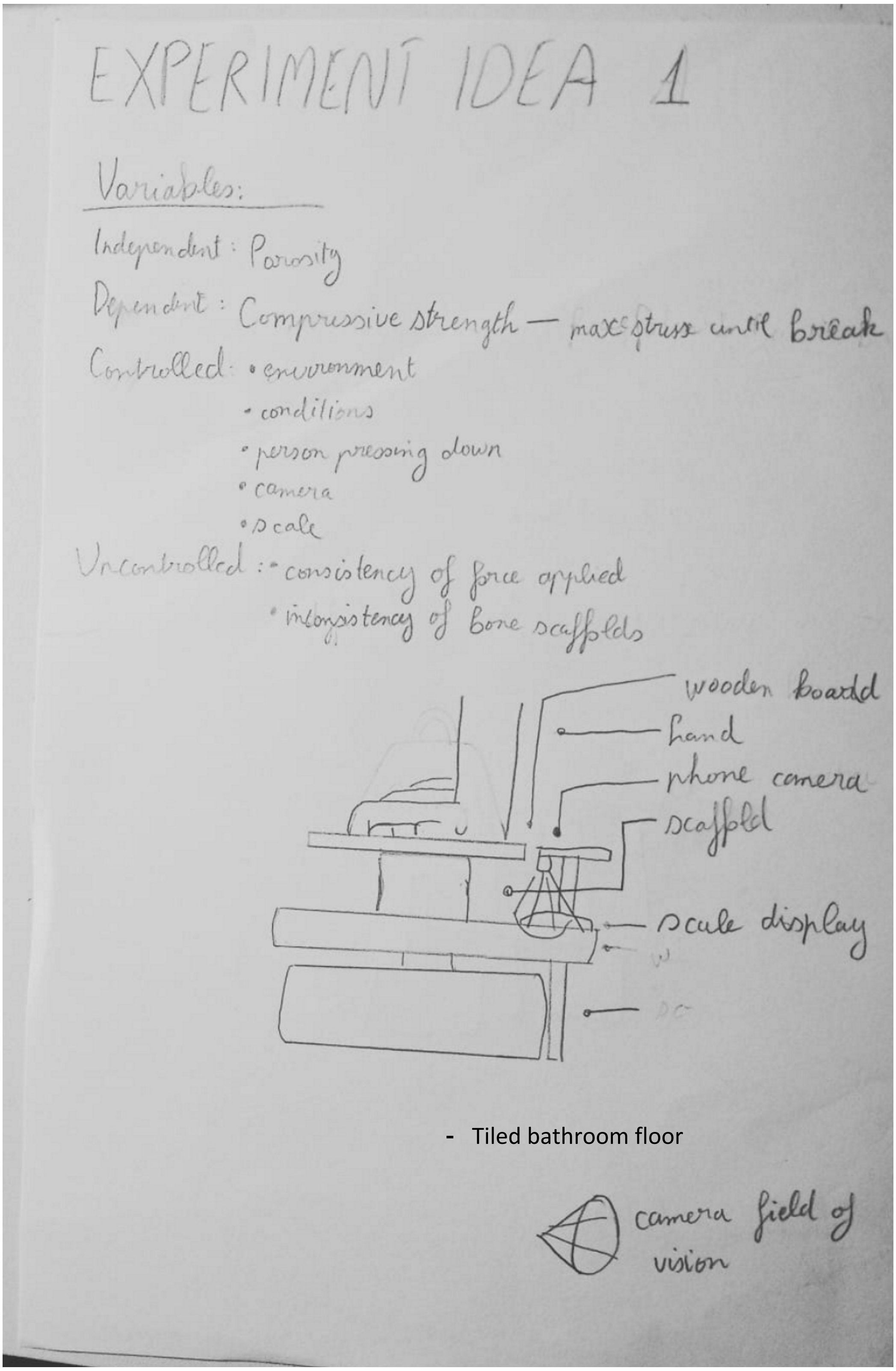
# B(ii) Develop a range of feasible ideas

Friday, March 12, 2021 11:15 AM

**B (ii)** develop a **range** of feasible design ideas, which can be correctly interpreted by others.

FORMAT: Series of annotated sketches

SKETCH and ANNOTE IDEA 1:



EXPERIMENT IDEA 1

Variables:

Independent : Porosity

Dependent : Compressive strength — max stress until break

Controlled:
- environment
- conditions
- person pressing down
- camera
- scale

Uncontrolled :
- consistency of force applied
- inconsistency of bone scaffolds

wooden board
hand
phone camera
scaffold
scale display
camera field of vision

- Tiled bathroom floor

# EXPERIMENT IDEA 2

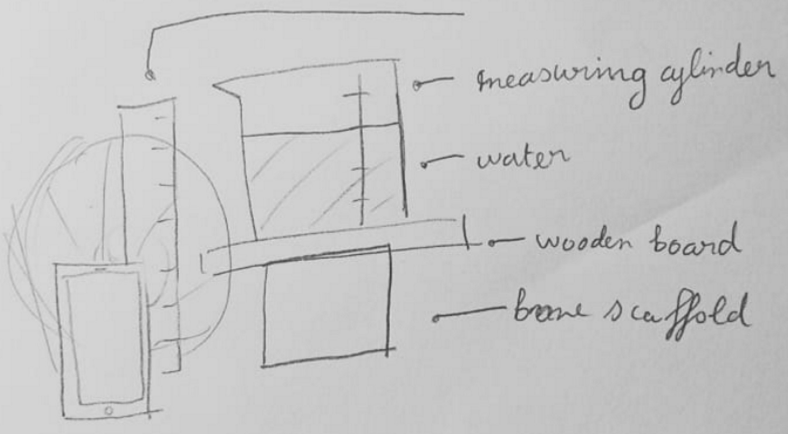
## Variables

Independent: Porosity

Dependent: Compressive strength – strain per stress applied

Controlled:
- environment
- conditions
- intervals of mass added
- camera
- water used
- intervals strain is measured
- mass added each time

Uncontrolled: inconsistency of bone scaffolds



- Tiled bathroom floor

camera field of vision

# EXPERIMENT IDEA 3

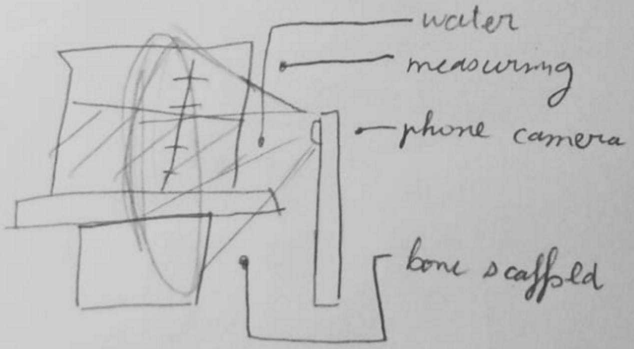
## Variables

Independent: Porosity

Dependent: Compressive strength – max stress until Break

Controlled:
- environment
- conditions
- intervals of mass added
- mass added each time
- camera

Uncontrolled:
- inconsistency of bone scaffolds



- Tiled bathroom floor

# B(iii) Present Chosen Design

Thursday, March 18, 2021 5:10 PM

**B(iii) Presented** the chosen process and **justified fully and critically** using feedback and with **detailed** reference to the design specification.

### STEP 1: Evaluate idea against success criteria

Examine each of your sketches and check against your success criteria. Copy your success criteria table, replace the columns to have these new columns:

| **Success Criteria** | **Sketch 1** Meets/ Partially meets/ Does not meet | **Sketch 2** Meets/ Partially meets/ Does not meet | **Sketch 3** Meets/ Partially meets/ Does not meet | **Overall comment** |
|---|---|---|---|---|
| Example: Experiment can be assembled and carried out in less than 10 minutes | Partially meets | Meets | Does not meet | Sketch 1 may take 12 minutes |
| The experiment must test the compressive strength of the bone scaffold | meets | Partially meets | meets | Sketch 2 is more accurate because it also measures how deformed the scaffold becomes before break |
| The experiment must be conducted on a level stable tiled floor | meets | meets | meets | Same variable for all 3 sketches |
| The experiment must be conducted in a low airflow $4m^2$ room (no openings over 50cm square) with temperature between 20℃ to 25℃ | meets | meets | meets | My bathroom is $4m^2$ and has no large openings |
| Experiment can be assembled and conducted in $1\leq30$ minutes | Partially meets | meets | meets | Sketch 1 is unsure because the intervals of the force being applied is inconsistent |
| The materials in the experiment must be household items with household-related primary purposes | meets | meets | meets | Measuring cylinders, wooden boards, rulers and water are household items |
| The trials must be recorded with a minimum 60fps camera in slow motion | meets | meets | meets | OPPO A73 has a 60fps camera with available slow motion mode. |
| The sole variable changed in the experiment must be porosity | meets | meets | meets | Same variable for all 3 sketches |
| All scaffolds must be printed using same printer | meets | meets | meets | Will be printed using the purple Prusa i3 Mk3 |
| The force applied to the bone scaffold in the experiment must be consistent | Does not meet | meets | meets | Manual force cannot be consistent in sketch 1 |

### STEP 2: Gather feedback from two peers

Now that you have analysed against the criteria, you may also show your peers and get any additional feedback. Jot down their feedback in point format

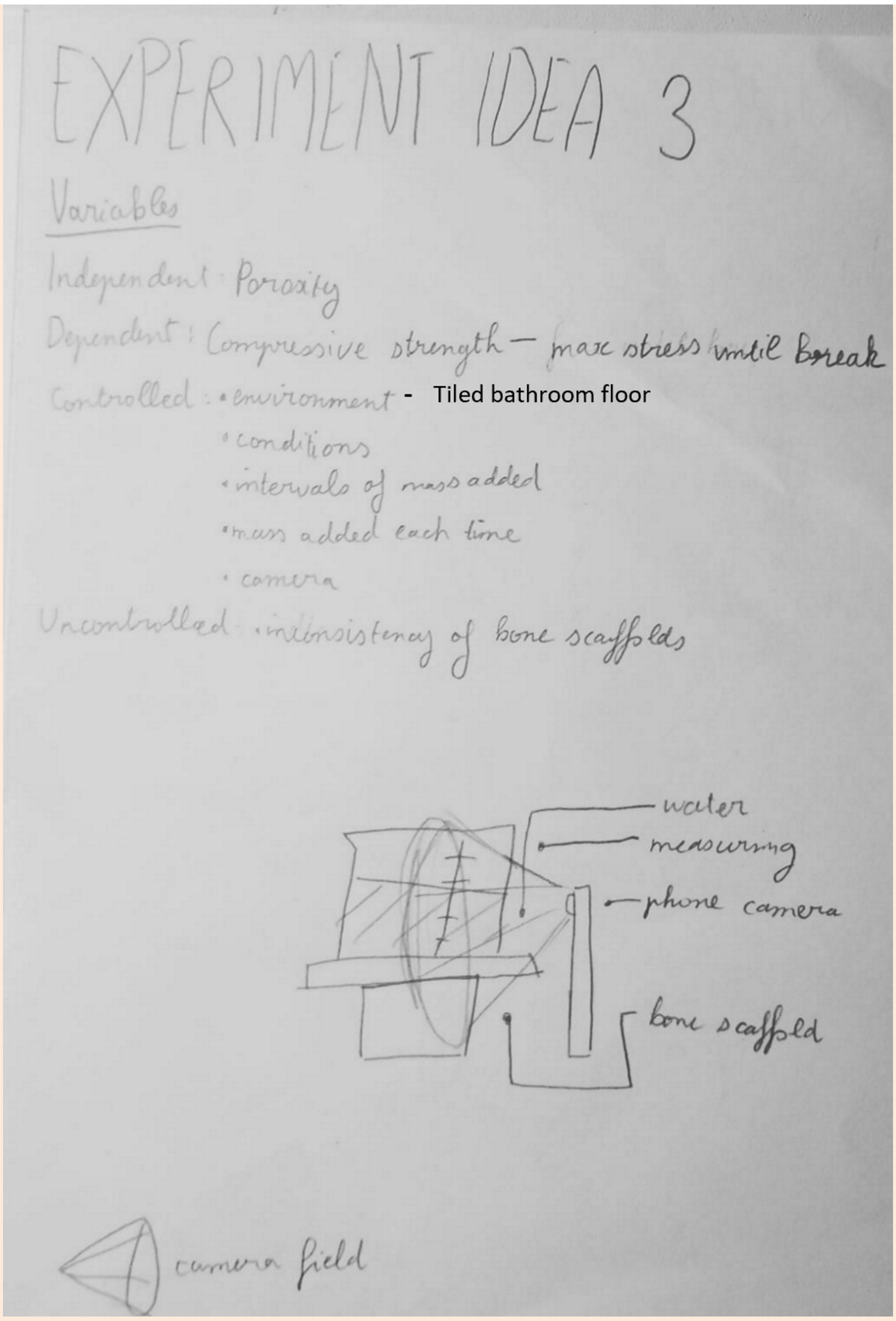
| Name of Peer | Date of feedback | Sketch 1 | Sketch 2 | Sketch 3 |
|---|---|---|---|---|
| Sara | March 18 | Quick to carry out<br>Measures strength more accurately that others<br>Do you have access to the equipment? | Better than Sketch 1 as less equipment but will it be accurate in measuring force? | The independent variable is not clear. What are you changing and what stays the same? |
| Soren | 18/3/21 | • The scale is accurate<br>• Foot would be a good alternative to hand because more force<br>• Conditions isn't controlled variable | • Measuring by how high up wooden board is accurate<br>• Displaying the data will be hard because you need to look at individual frames<br>• Conditions isn't controlled variable | • Conditions isn't controlled variable |
| Nikita | 18/3/21 | • Not sure you can break scaffold from pressing<br>• How will recording know when scaffold breaks | • Might need weights instead of water<br>• Water isn't heavy enough | • Phone not needed<br>• Weights instead of water |
| Alissa | 19/3/21 | • Using a scale to measure force is good<br>• Can be exhausting pressing on the scaffold | • Water idea is cool<br>• Ruler and stuff looks hard to set up<br>• Water might spill when bone scaffold breaks | • Looks good<br>• Water might spill |

**STEP 3: Quick Sketch of Final Design**

Using data from Step 1 and feedback from Step 2, in the box below, QUICKLY sketch out your final design.

Your final design may be:

- One of your three sketches (copied over from B(ii)
- An adaptation of one of the sketches
- A new idea based on feedback.



# EXPERIMENT IDEA 3

Variables

Independent: Porosity

Dependent: Compressive strength – max stress until Break

Controlled: • environment - Tiled bathroom floor
• conditions
• intervals of mass added
• mass added each time
• camera

Uncontrolled: • inconsistency of bone scaffolds

water
measuring
phone camera
bone scaffold
camera field

**STEP 4: Justification**

Give **two** key reasons (one short sentence each) explaining why you chose this final design.
For each reason, please give evidence to support this choice.

**YOUR TURN:**

| | |
|---|---|
| **Reason 1:** | Unlike sketch 1, the final design uses a consistent and accurate method of applying force. |
| **Evidence to support Reason 1:** | Human centre of gravity makes force applied to objects inconsistent and unstable. Water has a changing centre of gravity; but when placed in a container with stable positioning its centre of gravity is constant and the gravitational force it applies downwards is consistent and stable. |
| **Reason 2:** | Unlike sketch 2, the final design provides an accurate and straightforward method of measurement of the bone scaffold's compressive strength. |
| **Evidence to support Reason 2:** | Soren commented on sketch 2 that measuring the strain per individual frame using the ruler would be difficult and inaccurate. Additionally, the bone scaffold may not be elastic and break without strain after the peak amount of force is applied to it. |

# B(iv) Develop planning drawings or diagrams

Thursday, March 18, 2021 5:10 PM

**B (iv)** Develop accurate and detailed planning drawings/diagrams and outline the requirements for the creation of the chosen solution.

**FORMAT: detailed annotated diagram and a list of apparatus/materials**

Now that you have chosen your solution, you need to create a more detailed diagrams that includes measurements, materials and any steps that you need to create the experiment. You may have more than one step.

**STEP 1: Create Detailed Diagram(s)**

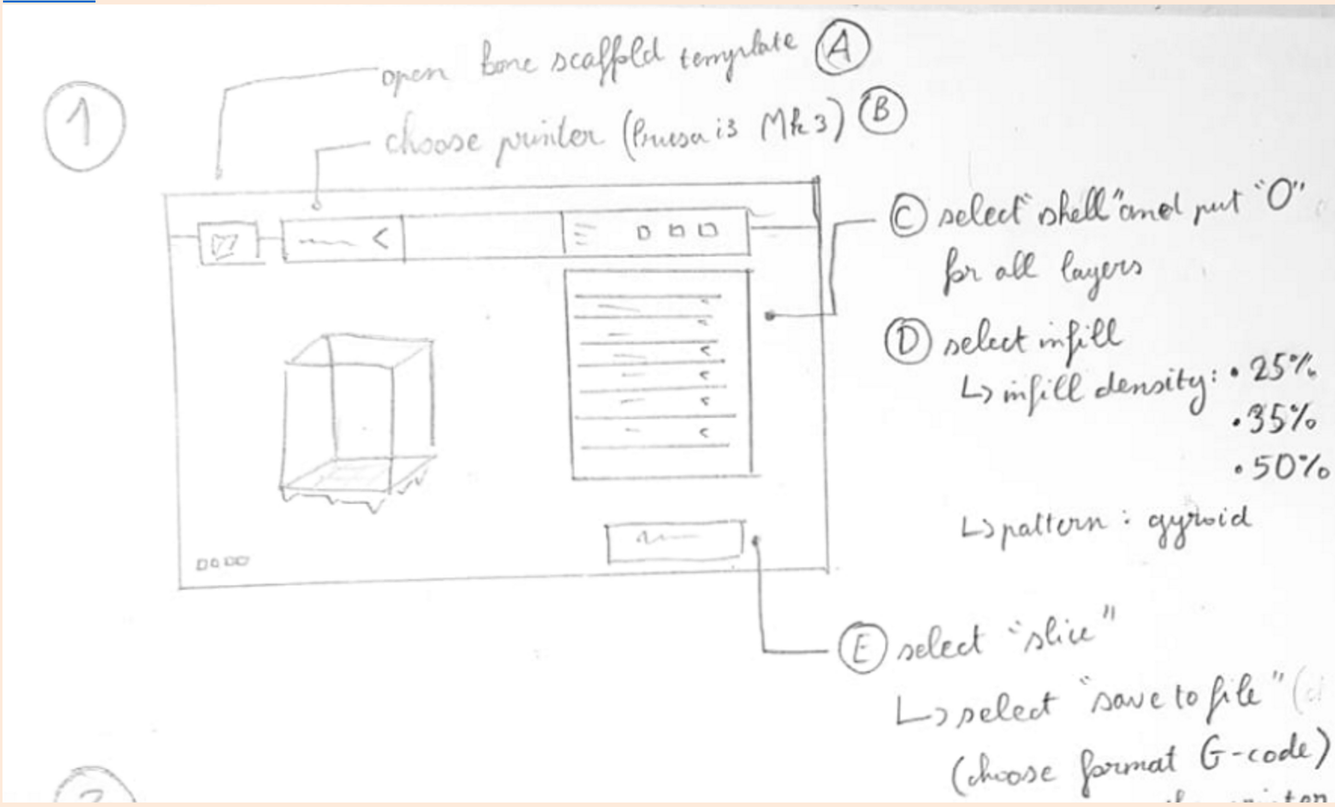
**Step-by-Step annotated detailed diagram(s) of your experiment(s)**

[detailed method + diagrams every step]

- Include printing

**FORMATTING GUIDE: BRIEF INSTRUCTION (NUMBERS) > INSTRUCTION BREAKDOWN (LETTERS) OR EQUIPMENT FOR REFERENCE (LETTERS)**

1. The scaffolds were designed (refer to 7: How will I make a bone scaffold from a 3D printer?) with specifications in STEP 2: Bone Scaffolds



open bone scaffold template Ⓐ

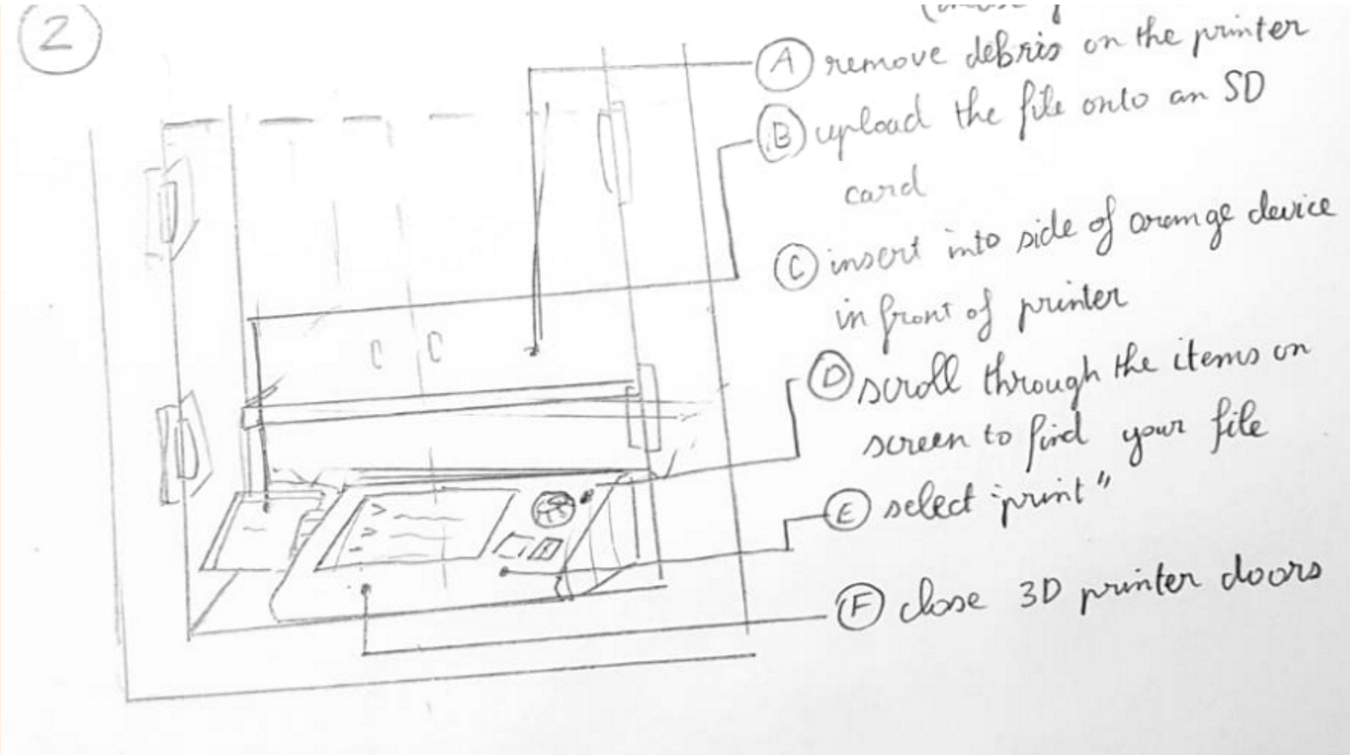
choose printer (Prusa i3 Mk3) Ⓑ

Ⓒ select "shell" and put "0" for all layers

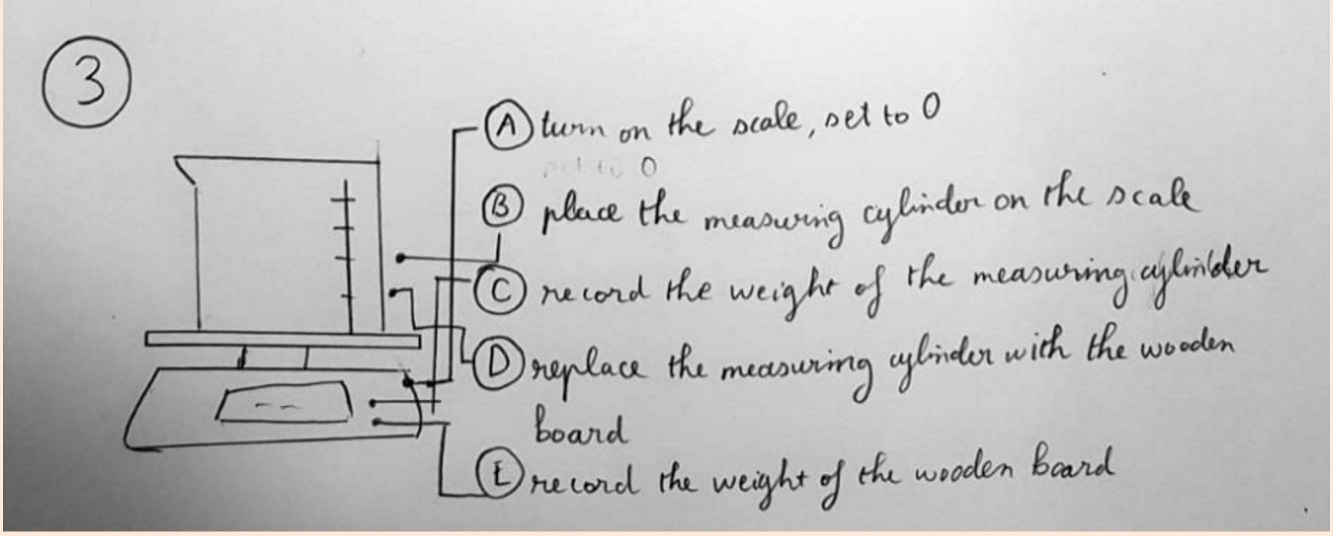
Ⓓ select infill
↳ infill density: • 25%
• 35%
• 50%
↳ pattern: gyroid

Ⓔ select "slice"
↳ select "save to file"
(choose format G-code)

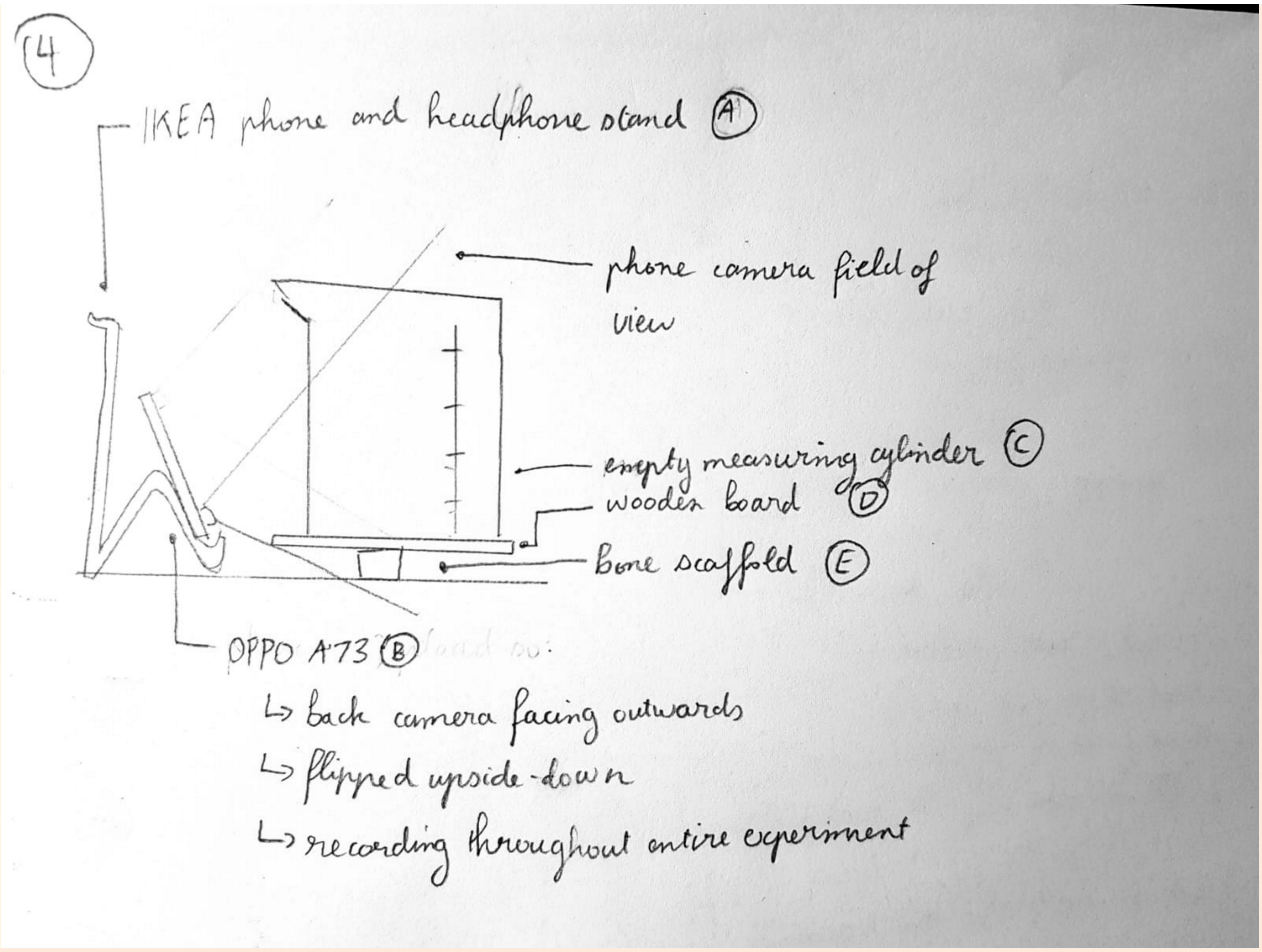
2. The scaffolds were printed


2
A remove debris on the printer
B upload the file onto an SD card
C insert into side of orange device in front of printer
D scroll through the items on screen to find your file
E select "print"
F close 3D printer doors

3. The weight of equipment that will be applied with the water was measured


3
A turn on the scale, set to 0
set to 0
B place the measuring cylinder on the scale
C record the weight of the measuring cylinder
D replace the measuring cylinder with the wooden board
E record the weight of the wooden board

4. The experiment was set up as following (side view):


④
IKEA phone and headphone stand Ⓐ
phone camera field of view
empty measuring cylinder Ⓒ
wooden board Ⓓ
Bone scaffold Ⓔ
OPPO A73 Ⓑ
↳ back camera facing outwards
↳ flipped upside-down
↳ recording throughout entire experiment

5. The bone scaffold (E) was the minimum porosity prototype
6. The phone began recoding (B)
7. the laptop timer app was set to 15 seconds
8. 250mL of tap water was poured into the measuring cylinder (C) and begin the timer
9. Should the bone scaffold (E) break within the 15 seconds, the amount of water in the cylinder (C) prior to breaking would have been recorded. The timer would have been reset to 15 seconds. Step 13 would have been skipped to.
10. Should the bone scaffold (E) not break within the 15 seconds, an additional 250mL would have been gradually poured into the measuring cylinder (C). The timer would have been reset to 15 seconds.
11. For the second interval, step 8 and 9 were repeated.
12. For the third interval, step 8 and 9 were repeated.
13. For the second trial, steps 6 to 11 were repeated.
14. For the third trial, steps 6 to 11 were repeated.
15. Water was removed from the measuring cylinder (C).
16. The bone scaffold (E) was replaced with the medium porosity prototype.
17. Steps 7 to 15 were repeated.
18. The bone scaffold (E) was replaced with the maximum porosity prototype.
19. Steps 7 to 15 were repeated.
20. The equipment were cleaned and stored. The bone scaffolds and bone scaffold fragments were recycled.

**STEP 2: Bone Scaffolds**

Please compete the specifications table below of bone scaffold(s) you will create using Cura.

You can add more rows and parameters if needed/known.

You may only want one set of the same scaffolds. If you testing different types of scaffold (your independent variable) then you may need to have 2 or 3 sets of scaffolds.

*Remember: the value of the independent variable is controlled by the experimenter, while the value of the dependent variable only changes in response to the independent variable.*

If you are not sure, don't worry as you can put TBD (to be decided) instead and you will need to experiment when we get to Criterion C as part of your techniques in creating the scaffolds.

| Name of scaffold (e.g. Infill 25%) | Infill | Pattern | Layer thickness | Laydown angles | Quantity to print |
|---|---|---|---|---|---|
| Minimum Porosity | 25% | Gyroid | 0.15mm | [0, 30, 0, 60, 0, 90] | 3 |
| Medium Porosity | 35% | Gyroid | 0.15mm | [0, 30, 0, 60, 0, 90] | 3 |
| Maximum Porosity | 50% | Gyroid | 0.15mm | [0, 30, 0, 60, 0, 90] | 3 |

### STEP 3: List of Materials/Resources/Apparatus

Please list all the materials/resources you will need that you have outlined your detailed diagram that you will need for your experiment. You do not need to add the information for bone scaffolds here as you have done this in Step 2.

Examples may be large analogue weighing scales, 50ml ethanol, 100ml measuring cylinder, cotton wool, tweezers.

| Item | Quantity | Details |
|---|---|---|
| 1L measuring cylinder | 1 | The container for the water |
| tap water | 1L | Water to act as weights to add to the measuring cylinder. Water will be gradually added to the cylinder each interval |
| 60fps camera OPPO A73 | 1 | For recording the experiment so the footage of point of break can be reviewed |
| 10kg electric kitchen scale | 1 | To measure weight of the wooden board and measuring cylinder |
| 20cmx10cmx1cm wooden board | 1 | To provide a flat surface for measuring cylinder to be placed on |
| Ikea phone and headphone stand | 1 | To position the phone to record the experiment |
| Laptop timer app | 1 | Determine intervals to add mass |

# Research Journal

Monday, February 8, 2021 11:27 AM

Your research journal is very important. It is where you record your research: it can be screen shots, notes from class, photos, experimental data.

You will organise your notes according to your research questions in A(ii).

# Key terms glossary & reference

Monday, 22 February 2021 10:30 AM

| Term | Reference |
|---|---|
| Force | • 1: What are properties of bone scaffolds?<br>• 4: How will I test my bone scaffold? |
| Pressure | • 1: What are properties of bone scaffolds?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold?<br>• 10: How can I give my bone scaffold a mechanical advantage? |
| Stress | • 5: What is Young's Modulus?<br>• 10: How can I give my bone scaffold a mechanical advantage? |
| Strain | • 5: What is Young's Modulus?<br>• 10: How can I give my bone scaffold a mechanical advantage? |
| Compression | • 1: What are properties of bone scaffolds?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold?<br>• 5: What is Young's Modulus?<br>• 10: How can I give my bone scaffold a mechanical advantage? |
| Tensile | • 1: What are properties of bone scaffolds?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold?<br>• 5: What is Young's Modulus? |
| Young's Modulus | • 5: What is Young's Modulus? |
| Sheer Force | • 1: What are properties of bone scaffolds?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold?<br>• 5: What is Young's Modulus? |
| Porosity | • 1: What are properties of bone scaffolds?<br>• 2: How do bones regenerate?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold? |
| Pore Size | • 1: What are properties of bone scaffolds? |
| Bone Density | |
| Bone scaffold | • 1: What are properties of bone scaffolds?<br>• 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold? |
| Calcium | |
| Cell Migration | • 2: How do bones regenerate? |
| 3D printing | • 3: What material is most suitable for this bone scaffold?<br>• 4: How will I test my bone scaffold?<br>• 7: How will I make a bone scaffold from a 3D printer? |
| Client | • 6: How will I present my idea?<br>• 9: Who is the consumer? |
| Consumer | • 6: How will I present my idea?<br>• 9: Who is the consumer? |

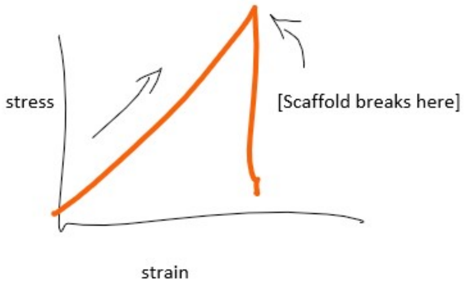
# Dr Hutmacher Lecture Notes Part 1

Monday, 8 February 2021 1:04 PM

- Engineers solve problems (eg bone defect fixed by scaffolds)
- Bioengineering is interdisciplinary field
- Oxford: big bio engineering institute - good info source
- Prof. Willem kolff - developed artificial kidney; dialysis - bad stuff in blood removed by filter/membrane
- Regenerative medicine > tissue engineering
- Things might work in lab but not irl - note
- Problem with scaffolds: hard to measure cross section of scaffolds (eg breast scaffold)
- Pore sizes matter
- Pore (x) : frequency (y) diagram
- Strain % (x) : stress (y) diagram
- Cellular materials (book) - good source - info abt pores, structures, patterns, density
- Displacement (x) : force (y) diagram
- Note elasticity
- **Material used in scaffolds:**
- titanium - good under compression, tensile strength, sheer pressure, bio compatible properties
- Biodegradable polymer - fairly strong, biodegradable (tissue can regrow inside and scaffold can degrade) by hydrolysis
- One pattern type/pore shape: honeycomb
- Less porosity = stronger (mechanical)
- More porosity = faster + safer regen (biological)
- Dilemma: biology or mechanical?
- Definition: the application of engineering principles, practices, and technologies to the fields of medicine and biology especially in solving problems and improving care (as in the design of medical devices and diagnostic equipment or the creation of biomaterials and pharmaceuticals)

About lecturer

- Mech engineering -> biomed engineering
- Did phd in singapore
- Regenerative med; regrow tissues
- Treated 26 yr old with tumour in leg: 40 hour surgery; 6 weeks to design scaffold



sources

Good points to consider

# Dr Hutmacher's Lecture Notes Part 2

Friday, 5 March 2021 11:06 AM

- Patient had bone infection in tibia
- Undetected for long time
- 35cm of bone affected
- Had to be removed
- Options: amputation or metal implant
- Procedures take 5-6 years
- Best designer: nature - strong and light
- Still allows biology - cells to move around
- Imitate biological structure
- Old school: replicate structure of bone to make scaffold
- NOT optimal ^^
- Completed bone - not natural
- New school: guide process of biology to point
- Structures/honeycombs
- Gympson & gabsidyaby: porous structures
- Strong as possible, little material as possible
- After year - scaffold starts degrading
- Scaffold degrade too quickly - bone regeneration not complete
- Bone grows into porous areas
- Enamel bone - healthy bone
- Russian mathematician - tessellation
- Multidisciplinary - engineers + mathematicians
- Built birds nest in beijing
- Architects need engineers to keep stable and appealing
- Computer scientists + engineers to execute designs thru 3d printers
- Sepecimens mechanically tested

# 1: What are properties of bone scaffolds?

Monday, February 8, 2021 11:30 AM

| Research Question(s) | What are properties of bone scaffolds? |
|---|---|

| | |
|---|---|
| Date | 8/2/21 |
| Source | Dr Hutmacher's lecture, class,<br>Dictionary by Merriam-Webster: America's most-trusted online dictionary. (2021). Retrieved 15 February 2021, from https://www.merriam-webster.com/ |
| Method of Collection | Notes |
| Type of research | Primary & secondary; qualitative |

**NOTES:**

Properties of bone scaffolds

| Property | Definition | Unit of measurement |
|---|---|---|
| Porosity | Porosity or void fraction is a measure of the void spaces in a material, and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. Strictly speaking, some tests measure the "accessible void", the total amount of void space accessible from the surface. | Percent (%) |
| Mechanical Strength | ability of a material or a mechanism to withstand an applied stress/strain or mechanical load without structural failure. | Pascal ($Pa$) |
| Tensile strength | maximum stress while being stretched or pulled before necking. | Pascal ($Pa$) |
| Compressive strength | capacity to withstand axially directed pushing forces. | Pascal ($Pa$) |
| Density | the degree of compactness of a substance. | Kilograms per cubic metre ($\frac{Kg}{m^3}$) |
| Elasticity | the ability of an object or material to resume its normal shape after being stretched or compressed; stretchiness. | Pascal ($Pa$) |
| Frequency | Frequency of pores within an area | Pores per square centimetre ($\frac{pores}{cm^2}$) |
| Pore size | How large the individual pores are | Millimetres square ($mm^2$) |
| Pattern/pore shape | The shape the pores are printed in | [quantitative] |

NOTE: properties of bone scaffolds can be used as independent variables to test the competency of the product

# 2: How do bones regenerate?

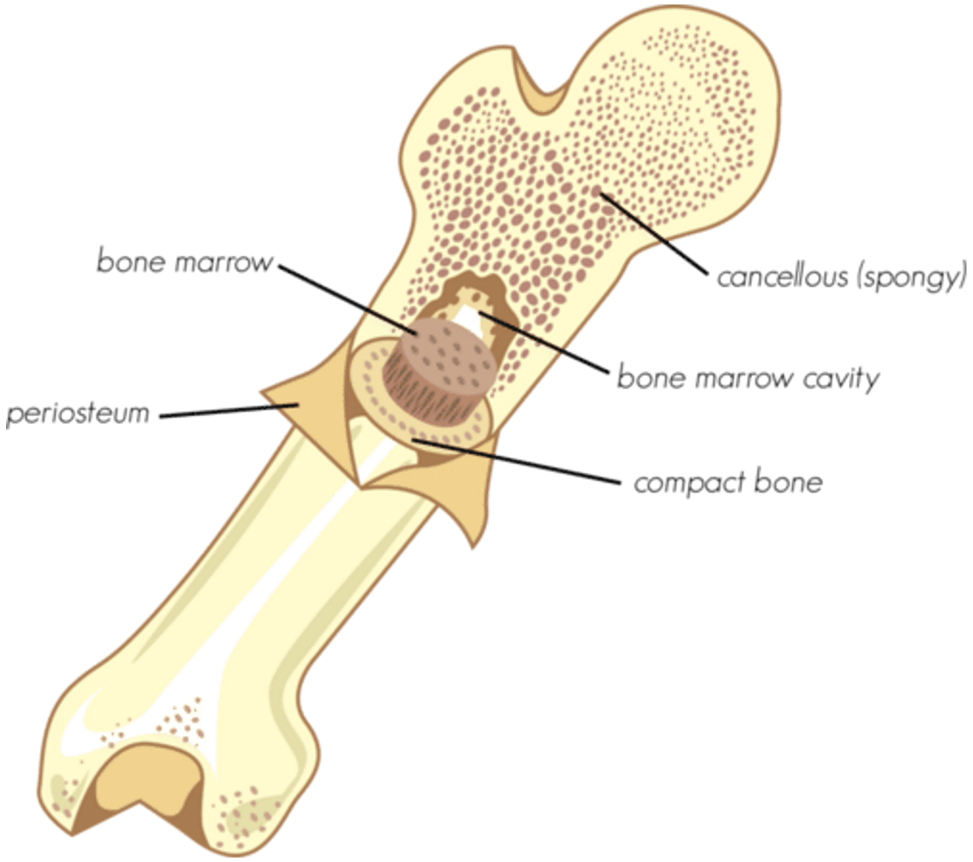
Monday, 15 February 2021 1:46 PM

| | |
|---|---|
| Research Question(s) | How do bones regenerate? |

| | |
|---|---|
| Date | 21/2/21 |
| Source | How do broken bones heal?. (2021). Retrieved 21 February 2021, from https://www.medicalnewstoday.com/articles/318961#Blood-comes-first<br>Bahney, C. Hu, D. Miclau III, T. Marcucio. (2015). The multifaceted role of the vasculature in endochondral fracture repair. Retrieved 21 Feburary 2021, from Frontiers \| The Multifaceted Role of the Vasculature in Endochondral Fracture Repair \| Endocrinology (frontiersin.org) |
| Method of Collection | Notes |
| Type of research | secondary; qualitative, quantitative |

Stages of bone regeneration:

- **Hematoma**: blood clots and pools in area around break, contains fracture debris, creates low pH microenvironment, creates porous fibrin network/temporary scaffold for inflammation to occur and cells to migrate
- **Inflammation**: initiation of immune cells, inflammatory cells -> pro-inflammatory cytokines -> polymorphonuclear neutrophils & microphages
- **Fracture repair**: pro-inflammation stage -> cell prefoliation & fibroblast growth factor & cell differentiation & bone morphogenetic protein
- **Anti-inflammation**: caused by phenotypic modulation of macrophages to m2 population in fracture callus. AI macrophages -> cytokines & growth factors -> tissue repair & angiogenesis



Key words:

- Scaffold
- Hematoma
- Inflammation
- Microphage - a small phagocytic blood cell, in particular a polymorphonuclear leucocyte; ingests foreign material
- Macrophage - a large phagocytic cell found in stationary form in the tissues or as a mobile white blood cell, especially at sites of infection, destroys foreign material
- Secrete - produce and discharge

# 3: What material is most suitable for this bone scaffold?

Monday, 15 February 2021 1:44 PM

| | |
|---|---|
| Research Question(s) | What material is most suitable for this bone scaffold? |

| | |
|---|---|
| Date | 8/2/2021 |
| Source | Dr Hutmacher's lecture |
| Method of Collection | Notes |
| Type of research | Secondary, qualitative |

**NOTES:**

**Material used in scaffolds:**

- **Titanium** - good under compression, tensile strength, sheer pressure, bio compatible properties
- **Biodegradable polymer** - fairly strong, biodegradable (tissue can regrow inside and scaffold can degrade) by hydrolysis

# 4: How will I test my bone scaffold?

Thursday, 18 February 2021    10:07 AM

| | |
|---|---|
| Research Question(s) | What material is most suitable for this bone scaffold? |

| | |
|---|---|
| Date | 18/2 |
| Source | Class |
| Method of Collection | Notes |
| Type of research | Primary, Quantative |

**NOTES:**

| Property/independent variable | Formula | Acronym meaning | Unit of measurement | Testing method | Materials required to test |
|---|---|---|---|---|---|
| Porosity | $\left(\frac{void}{total\ volume}\right)\%$ | Void= unused volume | Percent (%) | Finding impervious volume of scaffold through increase in volume of water and scaffold when scaffold is added to measuring cylinder | • 1X measuring cylinder 50mL<br>• 1X tap water 20mL<br>• 1X bone scaffold |
| Mechanical/compressive strength | $CS = \frac{F}{A}$ | CS= compressive strength<br>F = max force<br>A= OG cross section surface area | Pascal ($Pa$) | Finding how much mass applied to scaffold until breaking by pushing on scaffold on a bathroom scale | • 1X bathroom scale<br>• 1X wooden board<br>• 1X bone scaffold |
| Tensile strength | $TS = \frac{F}{A}$ | Ts= tensile strength<br>F= max force<br>A= OG cross-section surface area | Pascal ($Pa$) | Finding how much force until scaffold breaks by pulling on both sides of scaffold | • 1X pull newton scale 50N<br>• 2X string 20cm<br>• 1X camera<br>• 1X bone scaffold |
| Density | $P = \frac{m}{V}$ | P= density<br>m= mass<br>V = volume | Kilograms per cubic metre ($\frac{Kg}{m^3}$) | Finding mass and volume of scaffold through measurement | • 1X electric scale<br>• 1X bone scaffold<br>• 1X ruler 30cm |
| Elasticity | | | Pascal ($Pa$) | | |

# 5: What is Young's Modulus?

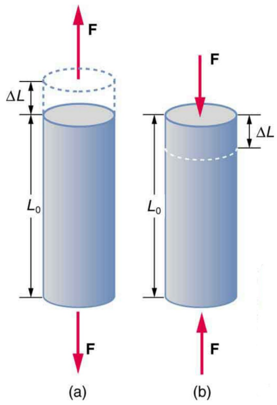
Thursday, 18 February 2021 10:03 AM

| | |
|---|---|
| Research Question(s) | What is Young's Modulus? |

| | |
|---|---|
| Date | 9/2/21 |
| Source | Class<br>Lumen. (ND). Boundless Physics: Elasticity, Stress, Strain, and fracture. Retrieved 9/2/21 at Elasticity, Stress, Strain, and Fracture \| Boundless Physics (lumenlearning.com) |
| Method of Collection | Notes |
| Type of research | Primary & secondary; qualitative |

**NOTES:**

| Term | Meaning | Acronym | Formula |
|---|---|---|---|
| Stress | is a measure of the force put on the object over the area. | $F$ | $\frac{force}{area}$ |
| Strain | is the change in length divided by the original length of the object. | $\triangle L$ | $\frac{change\ of\ whole}{whole}$ |
| Initial cross sectional surface | refers to dimensions or shape of cross section of specimens at the beginning of testing. | $L0$<br>OR<br>$\sigma$ | N/A |



Young's Modulus= $\frac{stress}{strain}$

Stress and Strain experiment

## How could we use marshmallows to demonstrate stress and strain?

### Aim

To measure the compression of an elastic material (marshmallow) as applied force is increased.

### Equations needed

To account for the cross sectional area $(A)$ of non-spring elastic objects, we would consider the force that is acting per square metre on the object. We use the quantity called **stress** $(\sigma)$.

$$\sigma = \frac{F}{A}$$

The ratio of the change in length and the original length is called the **strain** $(\epsilon)$. Strain is a dimensionless quantity.

$$\epsilon = \frac{\Delta L}{L}$$

The stress is directly proportional to the strain. The constant k is know as the Young's modulus, this constant varies depending on the elastic properties of the material.

$$\sigma = k\epsilon$$

### Equipment

- 1 or 2 mm graph paper (1 sheet)
- Electronic balance
- 4 wooden cube blocks (5x5x5 cm)
- 2 marshmallows
- 30 cm ruler (clear plastic preferred)
- 4 Brass Masses
- Blue tac

### Method

1. Measure initial height of the marshmallow
2. Measure the mass of the block and the empty beaker using the electronic balance
3. Adjoin a block and beaker *A* using blue tac.
4. Put graph paper on a cube using blue tac.
5. Configure the materials in the arrangement shown below:

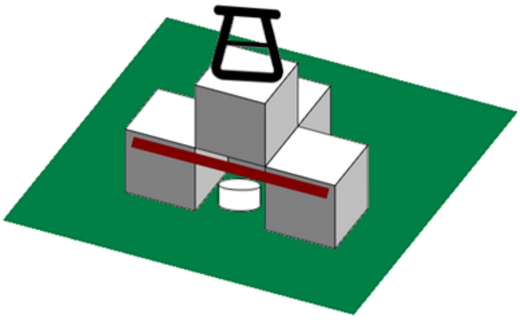


*Diagram 1. Experimental configuration.*

6. Gently add single masses to the top block and record the change in height of the marshmallow.
7. Continue adding individual masses till all four masses are on top of the marshmallow
8. Remove masses
9. Repeat *steps 7 – 12* for another trial using a new marshmallow.

### Variables

| | |
|---|---|
| Independent variable | Mass applied on marshmallow |
| Dependent variable | Height of marshmallow |
| Controlled variables | Marshmallow, environment |

**Risk Assessment**

| Source | Risk | Management Strategy |
|---|---|---|
| *Beaker* | *Broken glass can cause cuts* | - *Carefully place beaker on blocks use blue tac to prevent slipping*<br>- *Clean up all breakages immediately and dispose in sharps bin* |
| *Water* | *Spills cause slipping hazard* | - *Clean up all spills immediately* |
| *Electronic Scale* | *Electric shocks if wire is broken* | - *Make sure it is plugged in properly to avoid electrocution.*<br>- *Check wiring for damage each time before use.* |

## COMPLETE THE FOLLOWING TABLE AND SHOW CALCULATIONS - remember to consider the units you are using

Initial Marshmallow height:

Initial Marshmallow diameter:

| Mass (units) | Trial 1 Height (units) | Trial 2 Height (units) | Force (N) | Stress ($N/m^3$) | Strain | Youngs Modulus |
|---|---|---|---|---|---|---|
| 46.54g | 3.7 | 3.5 | 0.46 (2dp) | 4.53 (2dp) | | |
| 146.54g | 3.4 | 3.1 | 1.44 (2dp) | 4.57 (2dp) | | |

# 6: How will I present my idea?

Thursday, 18 February 2021 10:07 AM

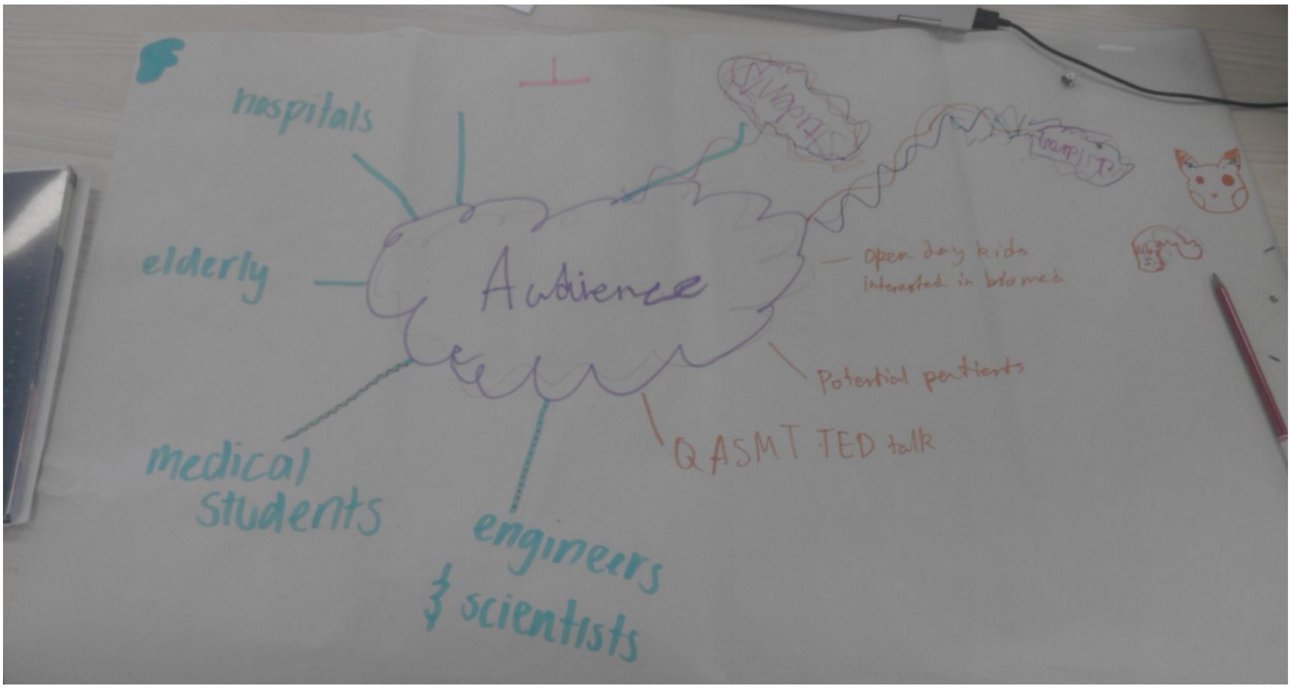
| | |
|---|---|
| Research Question(s) | How will I present my idea? |

| | |
|---|---|
| Date | 19/2/2020 |
| Source | Class discussion |
| Method of Collection | Notes |
| Type of research | Primary, qualitative |

**NOTES:**

| Form | Purpose | Audience/clients | Justification (statistical) |
|---|---|---|---|
| TEDx Talk, presentation with PowerPoint | Inform, promote | QASMT and parents,<br>medical experts, potential consumers, potential sponsors or investors | |
| Website | Inform, promote | Potential consumers, regenerative medicine experts, global community with access to internet, potential sponsors or investors | |
| Video | Inform | Potential consumers, global community with access to internet | |
| Fundraiser campaign | Promote | | |
| Pamphlet | Inform | Inform people at hospitals to consider regenerative medicine | • 82% of participants are not aware of the regenerative medicine field<br>• 36% of participants do not trust the field<br>• 73% of participants were or knew decision makers that did not consider regenerative medicine as an option |

Group discussion and brainstorm



Unpacking A(i)

- Who are the stakeholders/researchers involved in developing this treatment?
- Why is it important for patients, students and the wider community to know about this emerging field of study?
- Must have statistical data and evidence, e.g. 50% of Australians will get skin cancer
- Why is this fact significant to the audience
- Justify means to explain what it is, using the word because
- Explain the target audience and why they are important
- Using the word "because", you helps justified
- Include in-text citations
- Use evidence to support your ideas. Evidence could be quotes from internet research, notes from class discussion or resources. Cite them though out.  Remember examples plus evidence is your jusitifcation

# 7: How will I make a bone scaffold from a 3D printer?

Friday, 12 February 2021 11:17 AM

| | |
|---|---|
| Research Question(s) | How will I make a bone scaffold from a 3D printer? |

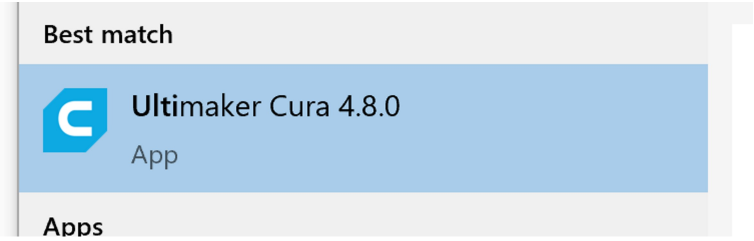
| | |
|---|---|
| Date | 9/2/21 |
| Source | class |
| Method of Collection | Notes |
| Type of research | Primary; qualitative |

**NOTES:**

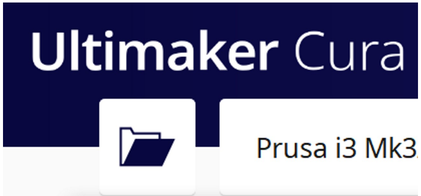
Bone scaffold examples:

Steps to printing bone scaffold:

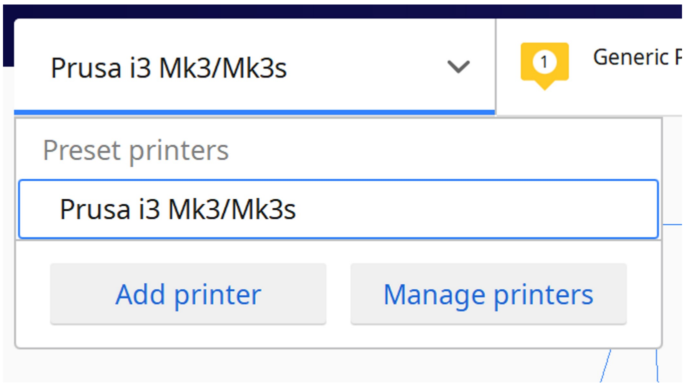
1. Open Ultimaker Cura



2. Open bone scaffold template

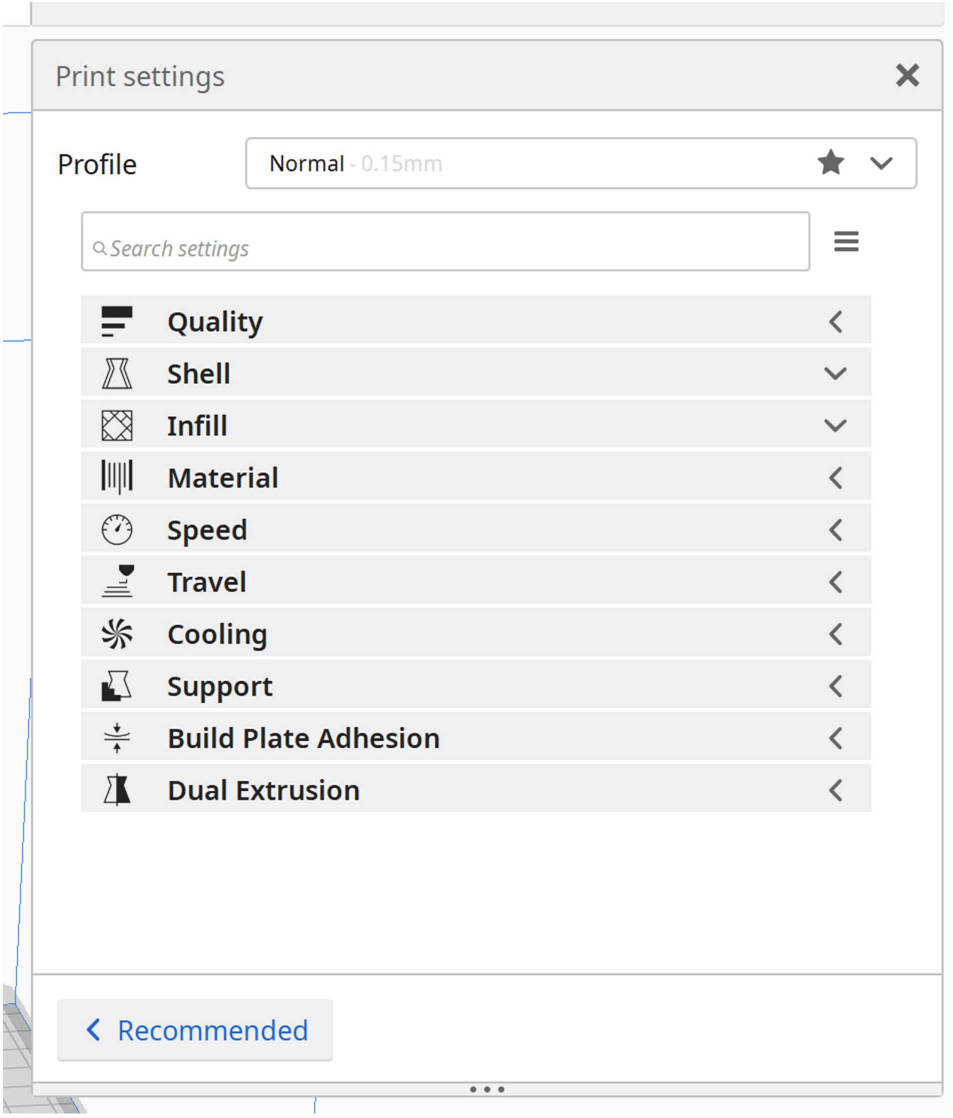


3. Select printer



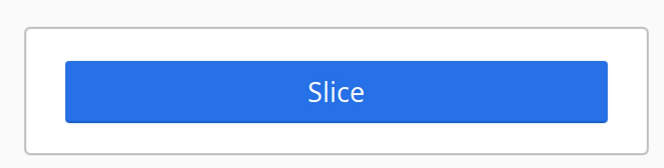
Prusa i3 Mk3/Mk3s

4. Modify bone scaffold through 'Print Settings'

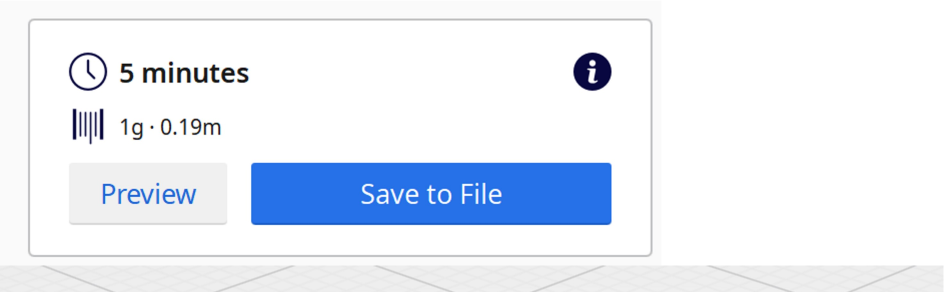


Profile Normal - 0.15mm

5. Select 'slice'



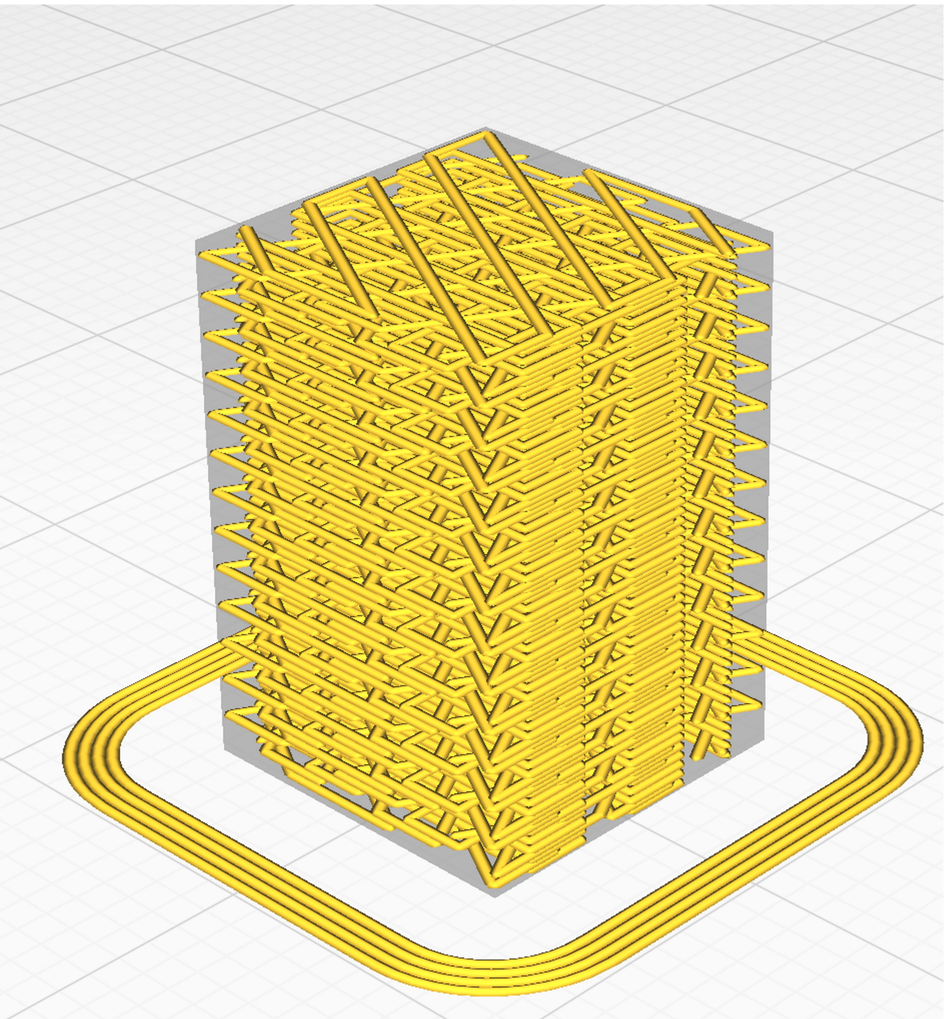
6. Preview the scaffold



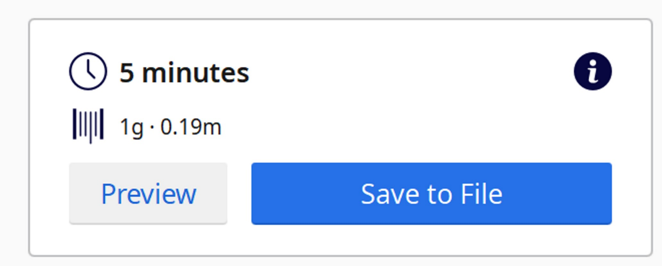
5 minutes

1g · 0.19m

7.

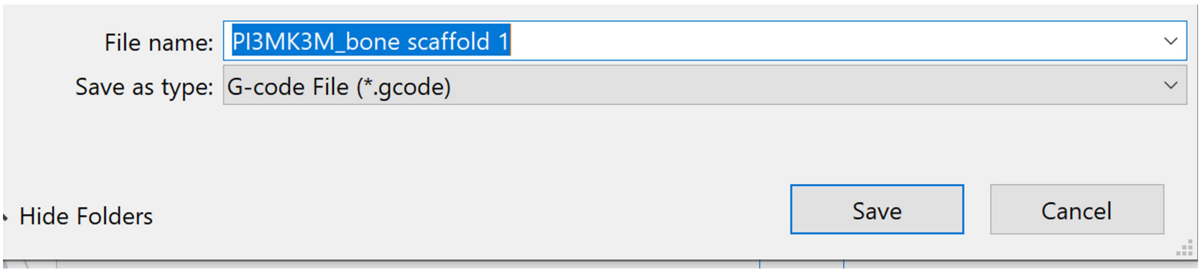


8. Save to file in G-code form



5 minutes

1g · 0.19m



File name: PI3MK3M_bone scaffold 1

Save as type: G-code File (*.gcode)

# 8: Why are 3d printers most suitable for making bone scaffolds?

Thursday, 18 February 2021 10:08 AM

| | |
|---|---|
| Research Question(s) | Why are 3d printers most suitable for making bone scaffolds? |

| | |
|---|---|
| Date | 21/2/21 |
| Source | Nawrat, A. (2018). 3D printing in the medical field: four major applications revolutionising the industry. Retrieved 21/2/21 at 3D printing in the medical field: four major applications revolutionising the industry - Verdict Medical Devices (medicaldevice-network.com).<br>Khatami, E. (2020). What is Medical 3d Printing - and How Is it Regulated? Retrieved 21/2/21 at What Is Medical 3D Printing and How Is it Regulated \| The Pew Charitable Trusts (pewtrusts.org) |
| Method of Collection | Notes |
| Type of research | Secondary, qualitative |

**NOTES:**

- Can modify to match patient's anatomy
- Precise - can mimic structure to scale of individual tissues
- Can print complex patterns
- Can use wider variety of materials both organic and artificial at great precision

# 9: Who is the consumer?

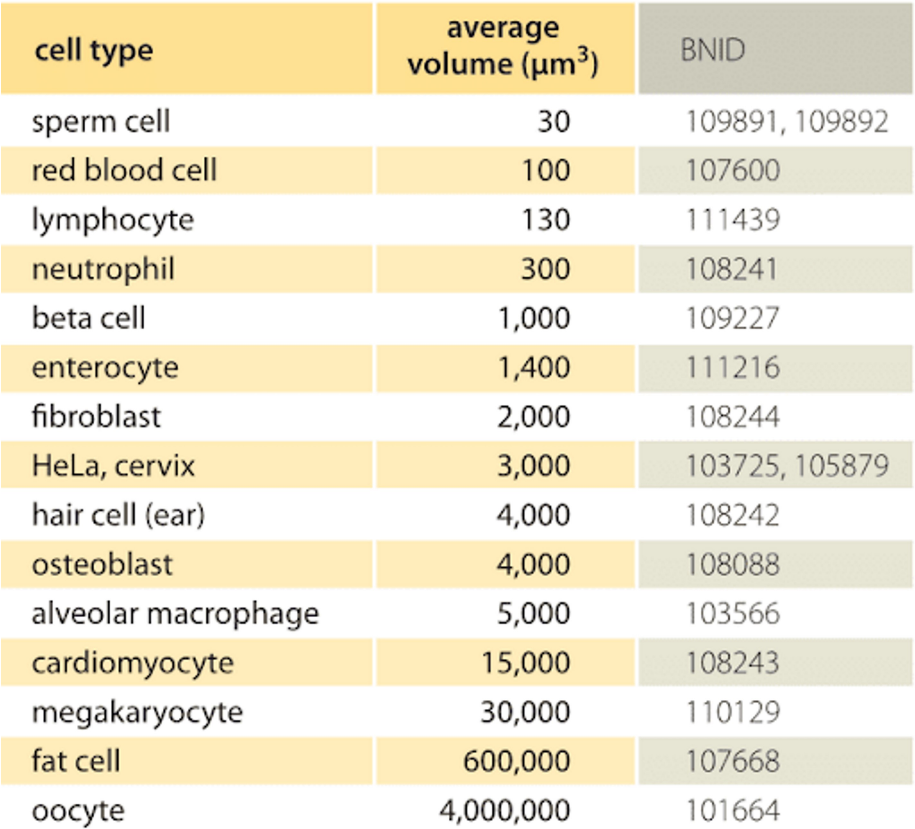
Thursday, 18 February 2021 10:08 AM

| Research Question(s) | Who is the consumer? |
|---|---|

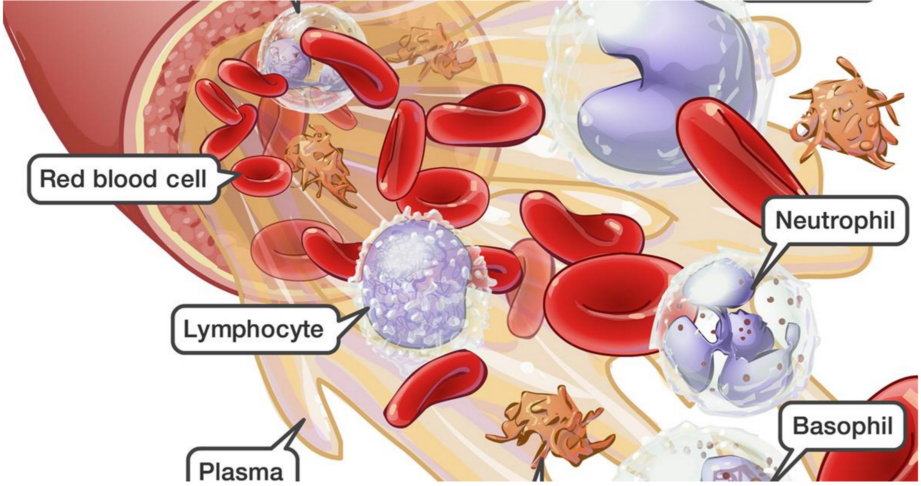
| | |
|---|---|
| Date | 18/2/21 |
| Source | Class,<br>https://www.researchgate.net/figure/A-A-47-year-old-male-patient-segmental-tibial-fracture-B-Reduction-technique-using_fig2_270613080<br>http://www.bioline.org.br/request?js07043#:~:text=Segmental%20tibial%20fractures%20are%20uncommon,often%20part%20of%20multiple%20injuries.<br>https://radiopaedia.org/articles/segmental-fracture-1<br>https://www.hhs.gov/fitness/resource-center/facts-and-statistics/index.html#:~:text=Physical%20Activity,are%20physically%20active%20every%20day.&text=Less%20than%205%25%20of%20adults,of%20physical%20activity%20each%20week.<br>What is the average weight of a 12 year old? Tables and guides (medicalnewstoday.com) |
| Method of Collection | Notes, survey |
| Type of research | Primary & secondary, qualitative & quantitative |

**NOTES:**

- Children under 12 - crucial bone development stage
- Children under 12 - 41kg
- Segmental fracture - bones break into 3 parts, 1 part is floating kinda
- Caused by high energy mech
- Tibia - leg bone between knee and ankle
- Seg frac 12.8% tibial fractures
- 50% open
- 70.2% complication rate
- 66% surgical intervention
- **How to fix:**
- Insert rod straight down bone
- Put on scews
- Keep leg in cast until most is healed
- Remove everything
- **Rods pros and cons:**
- Reliable - used for decades
- Sturdy & sustainable - titanium; good under compression, tensile strength, sheer pressure, bio compatible properties
- needs 2 surgeries - more prone to infection, complications, etc.
- Intrusive - has to drill into bone
- Affects bone growth
-



| cell type | average volume (μm$^3$) | BNID |
|---|---|---|
| sperm cell | 30 | 109891, 109892 |
| red blood cell | 100 | 107600 |
| lymphocyte | 130 | 111439 |
| neutrophil | 300 | 108241 |
| beta cell | 1,000 | 109227 |
| enterocyte | 1,400 | 111216 |
| fibroblast | 2,000 | 108244 |
| HeLa, cervix | 3,000 | 103725, 105879 |
| hair cell (ear) | 4,000 | 108242 |
| osteoblast | 4,000 | 108088 |
| alveolar macrophage | 5,000 | 103566 |
| cardiomyocyte | 15,000 | 108243 |
| megakaryocyte | 30,000 | 110129 |
| fat cell | 600,000 | 107668 |
| oocyte | 4,000,000 | 101664 |



Cells in a bone:

- Red blood cell
- Lymphocyte (white blood cells)
- Beta cell
- Fibroblast
- megakaryocyte

Human bone density:

- Around 1.24 ± 0.16 g/cm^2 (varies per bone & person)

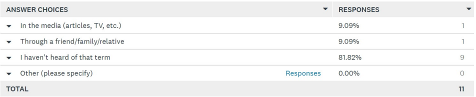
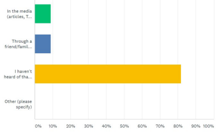
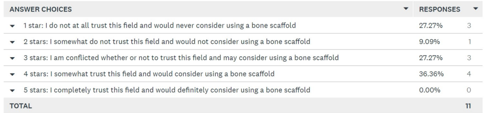
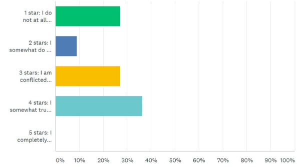
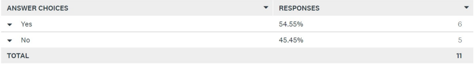
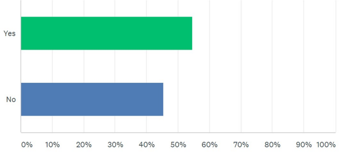
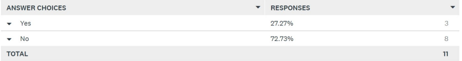
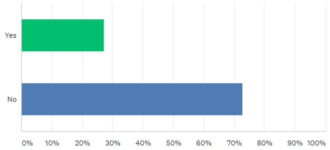
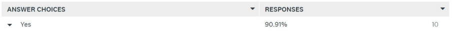
Consumers generally consider when buying products:

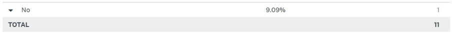
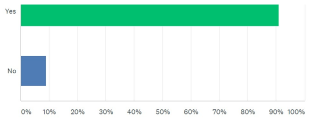
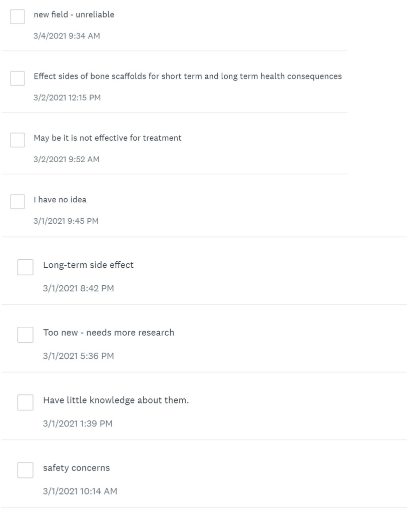
- Affordability
- Sustainability
- Environment friendly
- Functionality

SURVEY:
https://www.surveymonkey.com/r/B66ZJSY
Audience of survey: colleagues of mum - adults with wide range of occupations and fields, including medicine

| Question | Answer type | Data type | Justification/need for data |
|---|---|---|---|
| Where have you heard of the term 'Regenerative Medicine'? | Multiple choice | Qualitative | How informed the public is of bone scaffold and the sources informing the public |
| Based on what you currently know about the field, what is your opinion on regenerative medicine and bone scaffolds? [Out of 5 stars] | Star rating | Quantitative | Public opinion on scaffold in form of trust level and consideration |
| Do you know any close friends/family/relative under 12 years old that have gone through a bone fracture or break? | Yes/No | Quantitative | How common bone fractures or breaks are |
| Did the decision maker (the parent, guardian or themselves) in that situation consider using or chose to use a bone scaffold to mend the fracture? | Yes/No | Quantitative | How well-known regenerative medicine is in the real world. |
| Would you consider using a bone scaffold if the treatment was sponsored for research? | Yes/No | Quantitative | Whether removing the financial burden of treatment would affect decision making |
| What are some concerns you have about regenerative medicine or bone scaffolds? | Textbox | Qualitative | Concerns public has that may affect their commitment |

RESULTS:

| Question | Table | Graph |
|---|---|---|
| Where have you heard of the term 'Regenerative Medicine'? | <br>ANSWER CHOICES RESPONSES<br>In the media (articles, TV, etc.) 9.09% 1<br>Through a friend/family/relative 9.09% 1<br>I haven't heard of that term 81.82% 9<br>Other (please specify) Responses 0.00% 0<br>TOTAL 11 |  |
| Based on what you currently know about the field, what is your opinion on regenerative medicine and bone scaffolds? | <br>ANSWER CHOICES RESPONSES<br>1 star: I do not at all trust this field and would never consider using a bone scaffold 27.27% 3<br>2 stars: I somewhat do not trust this field and would not consider using a bone scaffold 9.09% 1<br>3 stars: I am conflicted whether or not to trust this field and may consider using a bone scaffold 27.27% 3<br>4 stars: I somewhat trust this field and would consider using a bone scaffold 36.36% 4<br>5 stars: I completely trust this field and would definitely consider using a bone scaffold 0.00% 0<br>TOTAL 11 |  |
| Do you know any close friends/family/relative under 12 years old that have gone through a bone fracture or break? | <br>ANSWER CHOICES RESPONSES<br>Yes 54.55% 6<br>No 45.45% 5<br>TOTAL 11 |  |
| Did the decision maker (the parent, guardian or themselves) in that situation consider using or chose to use a bone scaffold to mend the fracture? | <br>ANSWER CHOICES RESPONSES<br>Yes 27.27% 3<br>No 72.73% 8<br>TOTAL 11 |  |
| Would you consider using a bone scaffold if | <br>ANSWER CHOICES RESPONSES<br>Yes 90.91% 10 | |

| | | |
|---|---|---|
| the treatment was sponsored for research? | <br>No 9.09% 1<br>TOTAL 11 | <br> |
| What are some concerns you have about regenerative medicine or bone scaffolds? | <br>☐ new field - unreliable<br>3/4/2021 9:34 AM<br>☐ Effect sides of bone scaffolds for short term and long term health consequences<br>3/2/2021 12:15 PM<br>☐ May be it is not effective for treatment<br>3/2/2021 9:52 AM<br>☐ I have no idea<br>3/1/2021 9:45 PM<br>☐ Long-term side effect<br>3/1/2021 8:42 PM<br>☐ Too new - needs more research<br>3/1/2021 5:36 PM<br>☐ Have little knowledge about them.<br>3/1/2021 1:39 PM<br>☐ safety concerns<br>3/1/2021 10:14 AM | N/A |

# 10: How can I give my bone scaffold a mechanical advantage?

Thursday, 18 February 2021 10:09 AM

| | |
|---|---|
| Research Question(s) | What material is most suitable for this bone scaffold? |

| | |
|---|---|
| Date | |
| Source | Dr Huchmacher's lecture, Notes, Class experiment |
| Method of Collection | |
| Type of research | Secondary, qualitative |

**NOTES:**

Denser = stronger

# 11: How will my design process be recorded?

Thursday, 18 February 2021 10:21 AM

| | |
|---|---|
| Research Question(s) | What material is most suitable for this bone scaffold? |

| | |
|---|---|
| Date | |
| Source | Lecture |
| Method of Collection | |
| Type of research | Secondary, qualitative |

**NOTES:**

Attached is an exemplar of a year 10 student's design process.

| Feature | Example in exemplar |
|---|---|
| Structure | • Design situation<br>• Justify need<br>• Research plan<br>• Existing solutions<br>• Design brief |
| Research | • Existing solutions (ineffective and effective)<br>• Sociological studies<br>• Properties of materials<br>• Production<br>• Time constraints<br>• costs |
| | |
| | |
| | |
| | |
| | |

# 12: What are the key words in this unit and what do they mean?

Tuesday, 23 March 2021 11:34 AM

| | |
|---|---|
| Date | 8/2/21 |
| Source | Dr Hutmacher's lecture, class,<br>Dictionary by Merriam-Webster: America's most-trusted online dictionary. (2021). Retrieved 15 February 2021, from https://www.merriam-webster.com/ |
| Method of Collection | Notes |
| Type of research | Primary & secondary; qualitative |

Biomedical engineering: the application of engineering principles, practices, and technologies to the fields of medicine and biology especially in solving problems and improving care (as in the design of medical devices and diagnostic equipment or the creation of biomaterials and pharmaceuticals)

From <https://www.merriam-webster.com/dictionary/biomedical%20engineering>

Regenerative medicine: a branch of medicine concerned with developing therapies that regenerate or replace injured, diseased, or defective cells, tissues, or organs to restore or establish function and structure

From <https://www.merriam-webster.com/dictionary/regenerative%20medicine>

A bone scaffold is the 3D matrix that allows and stimulates the attachment and proliferation of osteoinducible cells on its surfaces. ... Various synthetic and natural, biodegradable and non-biodegradable materials have been used in the fabrication of bone scaffolds through different methods (11).

# C – Creating the Solution

Sunday, April 18, 2021 7:59 PM

**For a 7 or 8:**

**C(i) The student constructs a detailed and logical plan, which describes the efficient use of time and resources, sufficient for peers to be able to follow to create the solution**

For this task, you have constructed a detailed and logical plan, which describes the efficient use of time and resources, sufficient for peers to be able to follow to conduct the experiment(s).

**C(ii) The student demonstrates excellent technical skills when making the solution.**

*For this task:* You have demonstrated excellent technical skills in creating 3D printed models of scaffolds and preparing your experiment(s). These are documented in your process journal.

**C(iii) The student follows the plan to create the solution, which functions as intended and is presented appropriately.**

*For this task*: You have followed the plan to create and carry out your experiment(s) including data collection. You have documented the process in your process journal and presented the data that you have collected.

**C(iv) The student fully justifies changes made to the chosen design and plan when making the solution.**

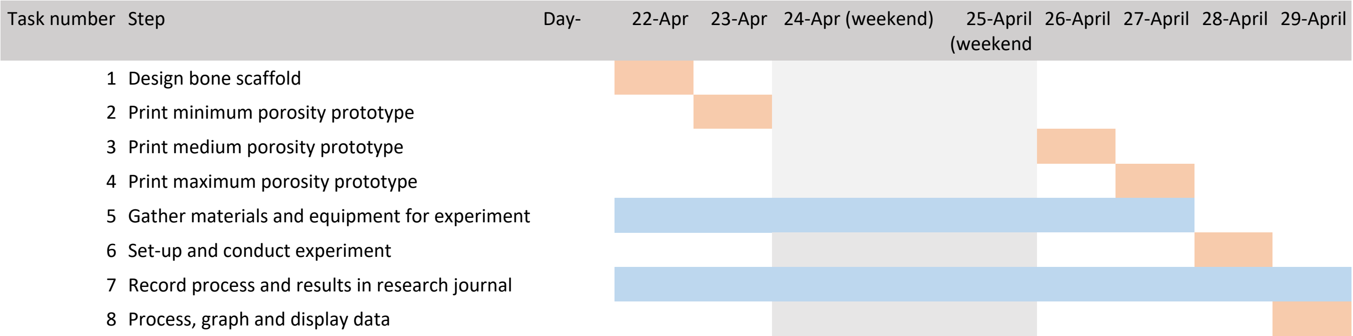
*For this task:* You have fully justified the changes made to the design plan and the plan when creating and carrying out your experiment(s).

# C(i) Construct a logical creation plan

Sunday, April 18, 2021 8:00 PM

| Task number | Task | Instructions reference | Materials and equipment needed | Success Criterion | Time required |
|---|---|---|---|---|---|
| 1 | Design bone scaffold | Refer to B(iv) Develop planning drawings or diagrams, step 1 | • 1x Ultimaker Cura 4.8.0 (software) | 3 files G-code files would have been created with specifications matching the ones designated to each model. | 20 minutes |
| 2 | Print minimum porosity prototype | Refer to B(iv) Develop planning drawings or diagrams, step 2 | • 1x Prusa i3 Mk3 | 3 complete samples of this model would have been made. | 34 minutes |
| 3 | Print medium porosity prototype | Refer to B(iv) Develop planning drawings or diagrams, step 2 | • 1x Prusa i3 Mk3 | 3 complete samples of this model would have been made. | 28 minutes |
| 4 | Print maximum porosity prototype | Refer to B(iv) Develop planning drawings or diagrams, step 2 | • 1x Prusa i3 Mk3 | 3 complete samples of this model would have been made. | 21 minutes |
| 5 | Gather materials and equipment for experiment | Refer to B(iv) Develop planning drawings or diagrams, step 4 | • 1x ikea phone stand 30cm<br>• 1x glass beaker 1L<br>• 1x tap water 4L<br>• 1x phone camera 60fps<br>• 1x bathroom scale 200kg<br>• 3x minimum porosity model samples 50% infill<br>• 3x medium porosity model samples 35% infill<br>• 3x maximum porosity model samples 25% infill<br>• 1x wooden board | All the materials stated would be readily available for use. | [ongoing until experiment date] |
| 6 | Set-up and conduct experiment | Refer to B(iv) Develop planning drawings or diagrams, steps 4 to 20 | [using materials and equipment gathered before experiment] | Raw data table would have been filled out with authentic data. All samples would have been used. | 30 minutes |
| 7 | Record process and results in research journal | Record in C(iii) Process Journal | N/A | Each task stated in this plan would have been recorded in the process journal. | [ongoing throughout process] |
| 8 | Process, graph and display data | Put data into tables, generate descriptive statistics, create graphs | • 1x Excel 2016 (software)<br>• 1x Tracker 4.8.0(software) | The data collected from task 7 would have been neatly sorted into tables, displayed in statistics, and represented in graphs. | 60 minutes |

The following is a Gantt chart visually displaying the sequence the experiment preparation and experiment will be carried in.



| Task number | Step | Day- | 22-Apr | 23-Apr | 24-Apr (weekend) | 25-April (weekend | 26-April | 27-April | 28-April | 29-April |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Design bone scaffold | | 🟧 | | ▨ | ▨ | | | | |
| 2 | Print minimum porosity prototype | | | 🟧 | ▨ | ▨ | | | | |
| 3 | Print medium porosity prototype | | | | ▨ | ▨ | 🟧 | | | |
| 4 | Print maximum porosity prototype | | | | ▨ | ▨ | | 🟧 | | |
| 5 | Gather materials and equipment for experiment | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | |
| 6 | Set-up and conduct experiment | | | | ▨ | ▨ | | | 🟧 | |
| 7 | Record process and results in research journal | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 |
| 8 | Process, graph and display data | | | | ▨ | ▨ | | | | 🟧 |

🟧 One lunch break or Biomedical Engineering lesson used actively for task

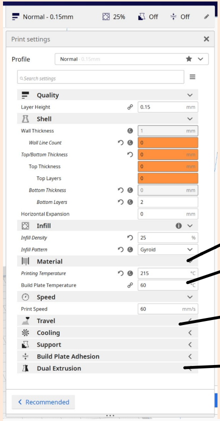
▨ Day unavailable for active task

🟦 Ongoing task done in free time outside of school

# C(ii) Evidence of Technical Skills

Sunday, April 18, 2021 8:03 PM

## Key Skill 1: Designing and printing bone scaffolds using Ultimaker Cura 4.8.0


Normal - 0.15mm 25% Off Off

Print settings

Profile: Normal - 0.15mm

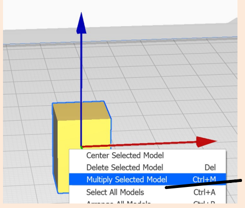
Quality
Layer Height: 0.15 mm
Shell
Wall Thickness: 1 mm
Wall Line Count: 0
Top/Bottom Thickness: 0 mm
Top Thickness: 0 mm
Top Layers: 0
Bottom Thickness: 0 mm
Bottom Layers: 2
Horizontal Expansion: 0 mm
Infill
Infill Density: 25 %
Infill Pattern: Gyroid
Material
Printing Temperature: 215 °C
Build Plate Temperature: 60 °C
Speed
Print Speed: 60 mm/s
Travel
Cooling
Support
Build Plate Adhesion
Dual Extrusion

Top and side walls set to 0 to remove walls to allow mobility for biologic cells to move in and out of scaffold (hypothetically)

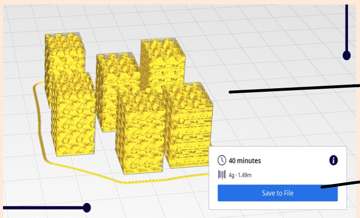
Set to 2 to make removing scaffold easier from plate without damaging the scaffold

Independent variable in experiment changed to 25% for medium porosity model

Added 15°C to the default because Prusa i3 Mk has higher required printing temperature than the Cura default setting

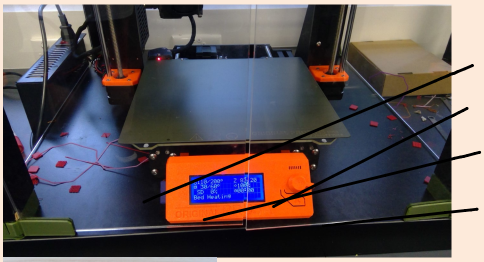


Multiplied samples to maximise printing time efficiency



Samples were spread out to prevent scaffolds from sticking with one another

After selecting slice then preview, the project was exported into G-code format since Prusa i3 supports G-code

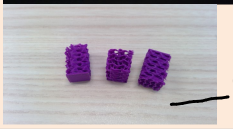


G-code file transferred onto SD card then into SD reader of printer

File selected by turning knob clockwise then pressing on knob

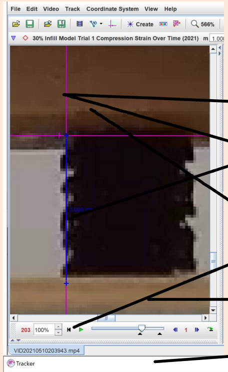
"Print" option selected to begin printing

Printer glass doors shut to prevent burns to people and keep printing environment stable



Completed product

## Key Skill 2: Transforming recording to raw data using Tracker 5.1.3


File Edit Video Track Coordinate System View Help
Create
30% Infill Model Trial 1 Compression Strain Over Time (2021)
VID20210510203943.mp4

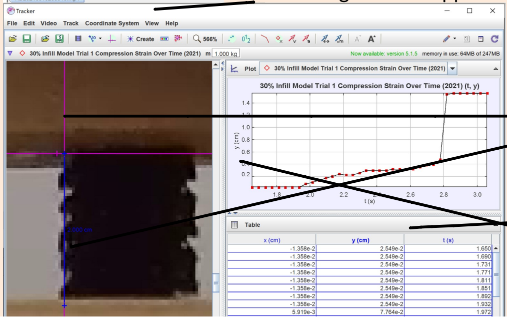
Selected Video > Filters > New > Rotate > -90° > Ok to rotate video upright

Selected Track > Axis and dragged axis origin to top left hand corner of scaffold to identify starting position of scaffold in able to calculate displacement in later steps

Selected Calibration stick icon> New > Calibration stick > shift + clicked and dragged from axis origin to bottom left corner of scaffold perpendicular to surface> measurement > Numbers > Units > centimetres > Ok > change to value "2". The calibration stick will be used as a reference measurement

Video was zoomed in for better viewing quality

Video length was cropped to the relevant parts when force was applied to when it was removed

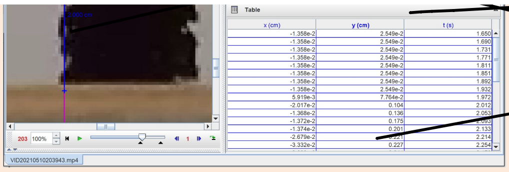

Tracker
File Edit Video Track Coordinate System View Help
Create
30% Infill Model Trial 1 Compression Strain Over Time (2021)
Plot
30% Infill Model Trial 1 Compression Strain Over Time (2021) (t, y)
y (cm)
t (s)
1.4
1.0
0.8
0.6
0.2
1.8
2.0
2.2
2.6
2.8
3.0
Table

| x (cm) | y (cm) | t (s) |
|---|---|---|
| -1.358e-2 | 2.549e-2 | 1.650 |
| -1.358e-2 | 2.549e-2 | 1.690 |
| -1.358e-2 | 2.549e-2 | 1.731 |
| -1.358e-2 | 2.549e-2 | 1.771 |
| -1.358e-2 | 2.549e-2 | 1.811 |
| -1.358e-2 | 2.549e-2 | 1.851 |
| -1.358e-2 | 2.549e-2 | 1.892 |
| -1.358e-2 | 2.549e-2 | 1.932 |
| 5.919e-3 | 7.764e-2 | 1.972 |

Selected Track > New > Point of Mass > mass A > shift + clicked on top leftmost of scaffold to record displacement of scaffold with reference to calibration stick. The frame would have automatically transitioned to the next. Shift + click on top leftmost of scaffold was repeated to end frame.

Selected x axis > t(s) and y axis y(cm) which will automatically format the graph to compare the displacement vs time

The raw data was imputed here and the relevant columns (x and t) can be exported into excel



Table

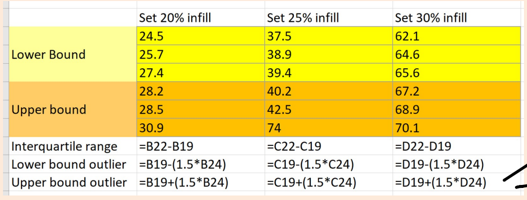
| x (cm) | y (cm) | t (s) |
|---|---|---|
| -1.358e-2 | 2.549e-2 | 1.650 |
| -1.358e-2 | 2.549e-2 | 1.690 |
| -1.358e-2 | 2.549e-2 | 1.731 |
| -1.358e-2 | 2.549e-2 | 1.771 |
| -1.358e-2 | 2.549e-2 | 1.811 |
| -1.358e-2 | 2.549e-2 | 1.851 |
| -1.358e-2 | 2.549e-2 | 1.892 |
| -1.358e-2 | 2.549e-2 | 1.932 |
| 5.919e-3 | 7.764e-2 | 1.972 |
| -2.017e-2 | 0.104 | 2.012 |
| -1.368e-2 | 0.136 | 2.053 |
| -1.372e-2 | 0.175 | 2.093 |
| -1.374e-2 | 0.201 | 2.133 |
| -2.679e-2 | 0.221 | 2.214 |
| -3.332e-2 | 0.227 | 2.254 |

Selected x axis > t(s) and y axis y(cm) which will automatically format the graph to compare the displacement vs time

The raw data was imputed here and the relevant columns (x and t) can be exported into excel for graphing.

**Key Skill 3: Graphing & displaying data using Excel 2016**

3.1: Outlier boundaries are required to remove outstanding data to improve accuracy of the descriptive statistics.



| | Set 20% infill | Set 25% infill | Set 30% infill |
|---|---|---|---|
| Lower Bound | 24.5 | 37.5 | 62.1 |
| | 25.7 | 38.9 | 64.6 |
| | 27.4 | 39.4 | 65.6 |
| Upper bound | 28.2 | 40.2 | 67.2 |
| | 28.5 | 42.5 | 68.9 |
| | 30.9 | 74 | 70.1 |
| Interquartile range | =B22-B19 | =C22-C19 | =D22-D19 |
| Lower bound outlier | =B19-(1.5*B24) | =C19-(1.5*C24) | =D19-(1.5*D24) |
| Upper bound outlier | =B19+(1.5*B24) | =C19+(1.5*C24) | =D19+(1.5*D24) |

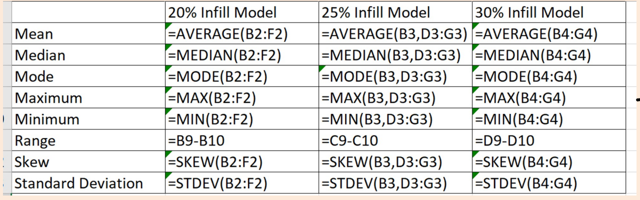
Outliers were found by organising the data sets by Select cells > Sort > Smallest to Largest > separate the bounds into lower and upper.

The interquartile range was found by subtracting the upper bound median from the lower bound median.

The lower bound outlier was found by subtracting the lower bound median by 1.5 times the interquartile range

The upper bound outlier was found by adding the low bound median by 1.5 times the IQR

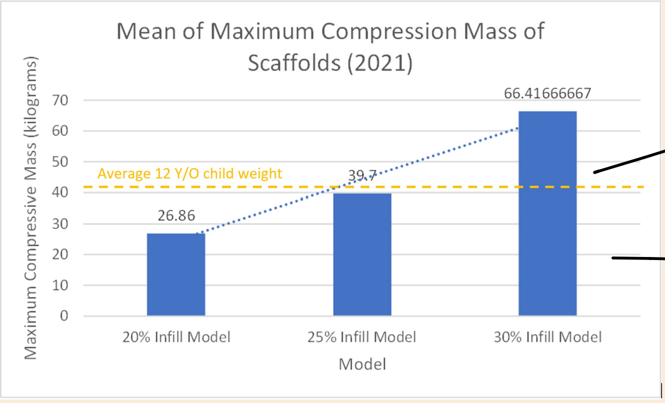
3.2: Descriptive statistics are required to identify statistical patterns or errors in the data



| | 20% Infill Model | 25% Infill Model | 30% Infill Model |
|---|---|---|---|
| Mean | =AVERAGE(B2:F2) | =AVERAGE(B3,D3:G3) | =AVERAGE(B4:G4) |
| Median | =MEDIAN(B2:F2) | =MEDIAN(B3,D3:G3) | =MEDIAN(B4:G4) |
| Mode | =MODE(B2:F2) | =MODE(B3,D3:G3) | =MODE(B4:G4) |
| Maximum | =MAX(B2:F2) | =MAX(B3,D3:G3) | =MAX(B4:G4) |
| Minimum | =MIN(B2:F2) | =MIN(B3,D3:G3) | =MIN(B4:G4) |
| Range | =B9-B10 | =C9-C10 | =D9-D10 |
| Skew | =SKEW(B2:F2) | =SKEW(B3,D3:G3) | =SKEW(B4:G4) |
| Standard Deviation | =STDEV(B2:F2) | =STDEV(B3,D3:G3) | =STDEV(B4:G4) |

With the outstanding data removed from the data set, the descriptive statistics were calculated using standard excel formulas and functions.

3.3: Graphing is required to visually display relevant data and patterns within the data.



A column graph was created by selecting cells B6:D6 (means of model sets) and selecting Insert > histogram icon > first design. The column type graph was chosen because the independent variable (x axis) is qualitative meaning they are sorted into categories, and are not quantitively relative; whereas the dependent variable (y axis) is quantitive and can be measured in a range.

Chart elements Axes, Axes Titles, Chart Title, Data Labels, Axis Range, Gridlines, and Trendlines were added to detail the graph

# C(iii) Process Journal

Sunday, April 18, 2021 8:16 PM

| Date | Time taken | Task | Key Skill in C(ii) | Change to plan | Change to design? |
|---|---|---|---|---|---|
| April 16th | 20 mins | Design bone scaffolds | 1 | Had to be updated over the weeks because default printing temperature is too low for | The prototypes' porosity were changed from 25%, 35%, 50% to 20%, 25%, 30%. Printed 6 samples for each model |
| April 22nd | 60 mins (split over several days) | Print bone scaffolds | 1 | Minimum and maximum porosity prototypes were mass printed so printing was reduced to 20 minutes | The prototypes' porosity were changed from 25%, 35%, 50% to 20%, 25%, 30%. Printed 6 samples for each model |
| Ongoing until May 3rd | Ongoing until May 3rd | Collect materials and equipment in preparation of experiment | N/A | N/A | The weight was replaced by a human weight because water weight was insufficient |
| May 3rd | 60 mins | Conduct experiments and record results | N/A | Had to be postponed back 2 days due to absence of medium porosity (25% infill) model set. | The weight was replaced by a human weight because water weight was insufficient |
| May 4th | 120 mins | Process, display, and graph data | 2, 3 | Had to be postponed back consequent to previous delays. Took 60 minutes longer than plan because of overestimation of abilities. | Stress vs time was also graphed to be used as reference for how the scaffold breaks. |

# Data Collection

Tuesday, 11 May 2021 7:37 PM

Original data

| Independent Variable (infill %) | Trial 1 Dependent Variable (kg) | Trial 2 Dependent Variable (kg) | Trial 3 Dependent Variable (kg) | Trial 4 Dependent Variable (kg) | Trial 5 Dependent Variable (kg) | Trial 6 Dependent Variable (kg) |
|---|---|---|---|---|---|---|
| 20% | 27.4 | 28.2 | 28.5 | 24.5 | 25.7 | 30.9 |
| 25% | 39.4 | 74 | 37.5 | 40.2 | 42.5 | 38.9 |
| 30% | 65.6 | 64.6 | 68.9 | 70.1 | 67.2 | 62.1 |

Outliers

| | Set 20% infill | Set 25% infill | Set 30% infill |
|---|---|---|---|
| Interquartile range | 2.8 | 3.6 | 4.3 |
| Lower bound outlier | 21.5 | 33.5 | 58.15 |
| Upper bound outlier | 29.9 | 44.3 | 71.05 |

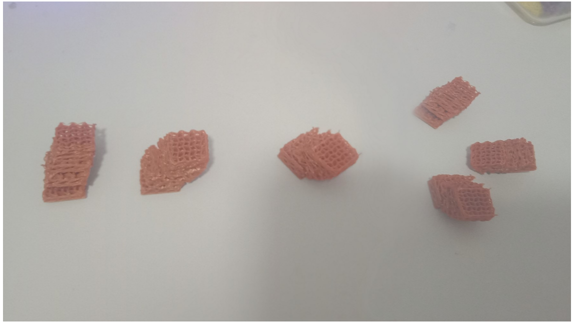
Data with outliers applied (green is within outliers, red is outside)

| Independent Variable (infill %) | Trial 1 Dependent Variable (kg) | Trial 2 Dependent Variable (kg) | Trial 3 Dependent Variable (kg) | Trial 4 Dependent Variable (kg) | Trial 5 Dependent Variable (kg) | Trial 6 Dependent Variable (kg) |
|---|---|---|---|---|---|---|
| 20% | 27.4 | 28.2 | 28.5 | 24.5 | 25.7 | 30.9 |
| 25% | 39.4 | 74 | 37.5 | 40.2 | 42.5 | 38.9 |
| 30% | 65.6 | 64.6 | 68.9 | 70.1 | 67.2 | 62.1 |

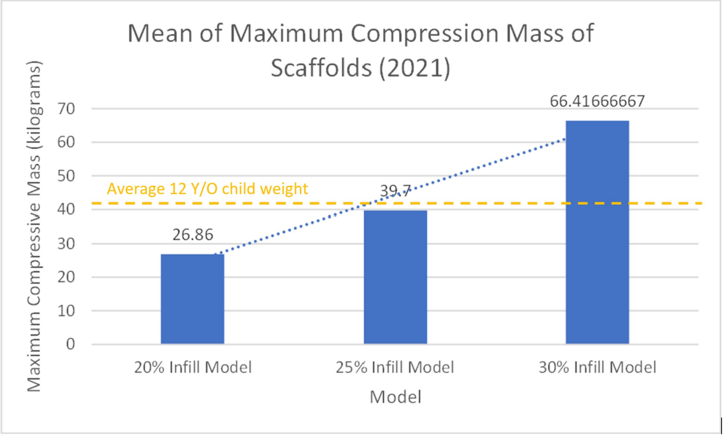
descriptive statistics with outliers applied

| | 20% Infill Model | 25% Infill Model | 30% Infill Model |
|---|---|---|---|
| Mean | 26.86 | 39.7 | 66.41667 |
| Median | 27.4 | 39.4 | 66.4 |
| Mode | #N/A | #N/A | #N/A |
| Maximum | 28.5 | 42.5 | 70.1 |
| Minimum | 24.5 | 37.5 | 62.1 |
| Range | 4 | 5 | 8 |
| Skew | -0.64456 | 0.719003 | -0.25274 |
| Standard Deviation | 1.709678 | 1.847972 | 2.930813 |

Crushed scaffolds (30% infill models):



Graph:

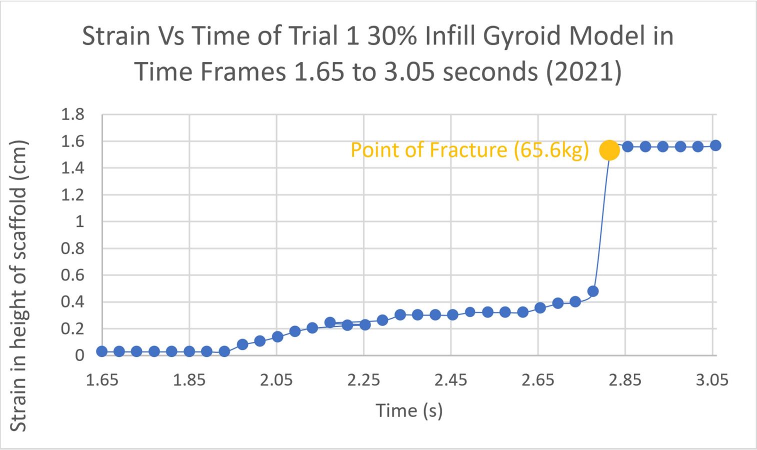


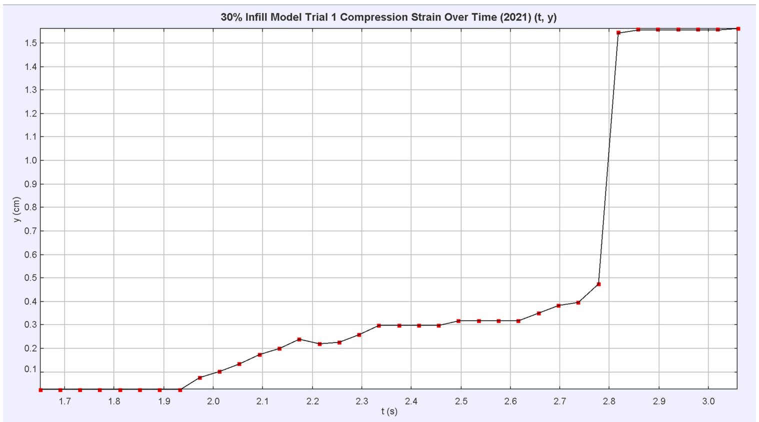
Children average mass under 12 (end consumer) - 41kg
30% infill - withstand [mean] 66.4kg (1dp)

Therefore, a randomised trial will be used to represent stress & strain performance of scaffold

Trial 1 (30% infill model) used as representative
Technology used: wheel of names randomiser, found at <[Wheel of Names | Random name picker]>

| strain (cm) | time (s) |
|---|---|
| 0.025491 | 1.650133 |
| 0.025491 | 1.690378 |
| 0.025491 | 1.730622 |
| 0.025491 | 1.770867 |
| 0.025491 | 1.811111 |
| 0.025491 | 1.851467 |
| 0.025491 | 1.891711 |
| 0.025491 | 1.931956 |
| 0.077641 | 1.9722 |
| 0.103683 | 2.012444 |
| 0.136271 | 2.052689 |
| 0.17537 | 2.092933 |
| 0.201436 | 2.133178 |
| 0.220974 | 2.213667 |
| 0.227484 | 2.253911 |
| 0.240529 | 2.173422 |
| 0.260067 | 2.294156 |
| 0.299183 | 2.3344 |
| 0.299183 | 2.374644 |
| 0.299183 | 2.414889 |
| 0.299183 | 2.455133 |
| 0.318733 | 2.495378 |
| 0.318733 | 2.535622 |
| 0.318733 | 2.575867 |
| 0.318733 | 2.616111 |
| 0.351321 | 2.656356 |
| 0.383904 | 2.696711 |
| 0.396937 | 2.736956 |
| 0.475135 | 2.7772 |
| 1.543827 | 2.817444 |
| 1.556883 | 2.857689 |
| 1.556883 | 2.897933 |
| 1.556883 | 2.938178 |
| 1.556883 | 2.978422 |
| 1.556883 | 3.018667 |
| 1.5634 | 3.058911 |



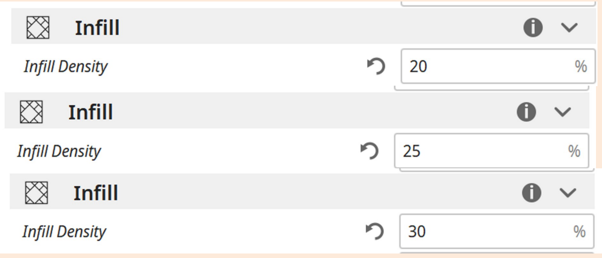


[excel version labeled and stuff here]

# C(iv) Justifying changes to the creation plan

Sunday, April 18, 2021 8:23 PM

**Maximum 1 x A4 page 250 words**

| **Description of change** (may include screenshot) | **Is this a Design or Planning change?** | **Which key success criteria are affected?** | **Outline of your justification of Change** |
|---|---|---|---|
| **First Change:**<br>Changing settings for each of the prototypes from 25%, 35%, 50% to 20%, 25%, 30%.<br><br>Infill<br>Infill Density 20 %<br>Infill<br>Infill Density 25 %<br>Infill<br>Infill Density 30 % | Design | The sole variable changed in the experiment must be porosity | Models gyroid 20% and 30% were readily available meaning the printing time could be reduced by 66%. Additionally, the pre-change minimum porosity prototype (50% infill) pores were smaller than 300µm, which is the minimum for megakaryocyte cells to manoeuvre throughout the scaffold. This discovery affected the independent variable success criterion because changing porosity consequently changed pore size. To keep the pore sizes the most similar, the difference between infills was kept at a minimum of 5% infill difference between each model.<br>Therefore the infill settings for each of the scaffolds were changed to 20%, 25%, and 30%. |
| **Second Change:**<br>Type of weight applied onto scaffold was changed from 1L water weight to a 71kg human weight.<br> | Design | The force applied to the bone scaffold in the experiment must be consistent | After testing conducting the original experiment, the 1L body of water was unsuccessful in fracturing the scaffold. Weights above 1kg were not household items and by using them would affect the household items success criterion. However human weight, which is considered a household item because of their accessibility, are significantly heavier than the water weight. Although human weights are less reliable because they are difficult to control having constantly shifting centres of gravity, human weights are still a better alternative. |
| **Third Change:**<br>Number of samples for each model changed from 3 samples and trials to 6<br> | Design | N/A | After testing the 25% infill model, an outstanding data which shifted the mean to median difference to 10kg. To generate outliers, more at least 6 trials were needed to separate the data set into 2 bounds. By removing outstanding data with outlier bounds, more trials overall improves accuracy of the descriptive statistics and graphs. |

# D - Evaluation

Monday, May 3, 2021 7:38 AM

For a 7-8, the student:

D(i) The student designs detailed and relevant testing methods, which generate data, to measure the success of the solution

**In Criterion C, I have designed detailed and relevant testing methods, which generate data to measure the success of my experimental process. This includes:**

- **selecting testing method(s) appropriate for this context**
- **carrying out authentic testing**

In D(i), I have analysed the data from C and presented my findings appropriately.

D(ii) The student critically evaluates the success of the solution against the design specification based on authentic product testing

**For this task, I have critically evaluated product against the design specification based on testing.**

D(iii) The students explains how the solution could be improved

**For this task, I have explained (with detailed reasons) ways my experiment(s) and/or 3D models could be improved**

D(iv) The student explains the impact of the product on the client/target audience.

**For this task, I have explained the impact of my experiment(s) on my client/target audience.**

Evidence for D(i) and D(iii) may be presented with C(ii), C(iii) and C(iv)

# D(i) Analysis of Data

Monday, May 3, 2021 7:44 AM

Figure 1: Outliers

| | Set 20% infill | Set 25% infill | Set 30% infill |
|---|---|---|---|
| Interquartile range | 2.8 | 3.6 | 4.3 |
| Lower bound outlier | 21.5 | 33.5 | 58.15 |
| Upper bound outlier | 29.9 | 44.3 | 71.05 |

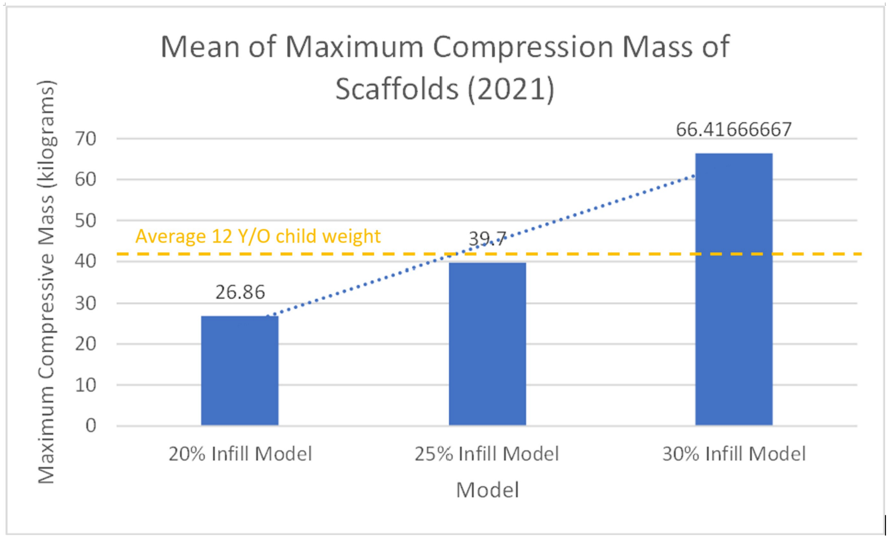
Figure 2: Raw data with outliers applied (green is within outliers, red is outside)

| Independent Variable (infill %) | Trial 1 Dependent Variable (kg) | Trial 2 Dependent Variable (kg) | Trial 3 Dependent Variable (kg) | Trial 4 Dependent Variable (kg) | Trial 5 Dependent Variable (kg) | Trial 6 Dependent Variable (kg) |
|---|---|---|---|---|---|---|
| 20% | 27.4 | 28.2 | 28.5 | 24.5 | 25.7 | 30.9 |
| 25% | 39.4 | 74 | 37.5 | 40.2 | 42.5 | 38.9 |
| 30% | 65.6 | 64.6 | 68.9 | 70.1 | 67.2 | 62.1 |

Figure 3: Descriptive statistics with outliers applied

| | 20% Infill Model | 25% Infill Model | 30% Infill Model |
|---|---|---|---|
| Mean | 26.86 | 39.7 | 66.41667 |
| Median | 27.4 | 39.4 | 66.4 |
| Mode | #N/A | #N/A | #N/A |
| Maximum | 28.5 | 42.5 | 70.1 |
| Minimum | 24.5 | 37.5 | 62.1 |
| Range | 4 | 5 | 8 |
| Skew | -0.64456 | 0.719003 | -0.25274 |
| Standard Deviation | 1.709678 | 1.847972 | 2.930813 |

Figure 4: Mean of Maximum Compression Mass of Scaffolds (2021) - graph



Outliers were used to rule out outstanding data to maintain the accuracy of the data sets (refer to figure 1). The values of mean and median are extremely close with each other (figure 3). This is because the data sets' standard deviation is focused near the mean as shown in the standard deviation row. The skewness is near symmetrical, as shown the skew row(refer to figure 3, meaning the raw data is somewhat quantitatively relative and reliable.

Therefore, the central tendency of this data set is the mean because the data's standard deviation is positioned close to the mean and the skewness indicates that the data surrounding the mean are fairly symmetrical and accurate. Using the mean as the central tendency, graphs and visual diagrams can be made surrounding it. A column graph (refer to figure 4) was used to represent the data because the independent variable (x axis) is qualitative meaning they are sorted into categories, and are not quantitively relative; whereas the dependent variable (y axis) is quantitive and can be measured in a range.

# D(ii) Evaluate against Design Specifications

Monday, May 3, 2021 8:04 AM

**Maximum 1 x A4 page**

| **Success Criterion** *from B(i)* | **Met**<br>**Partially Met**<br>**Not Met** | **Evaluative Comment (1 sentence per criterion)** |
|---|---|---|
| The experiment must test the compressive strength of the bone scaffold | Met | The experiment tested the mechanical compressive strength of the bone scaffold measured by mass (kg) required to fracture scaffold. |
| The experiment must be conducted on a level stable tiled floor | Met | The experiment was conducted on a still and flat tiled bathroom floor. |
| The experiment must be conducted in a low airflow $4m^2$ room (no openings over 50cm square) with temperature between 20℃ to 25℃ | Partially Met | The bathroom that the experiment had been carried out in was $4m^2$ with low airflow (the door was closed) and had a temperature of 27℃. |
| Experiment can be assembled and conducted in 1≤30 minutes | Not met | The experiment was assembled and conducted in approximately 60 minutes. |
| The materials in the experiment must be household items with household-related primary purposes | Met | All materials were household items. |
| The trials must be recorded with a minimum 60fps camera in slow motion | Met | The camera used had 60fps slow motion. |
| The sole variable changed in the experiment must be porosity | Not met | Because pore size is directly proportional to porosity, the pore size also became an independent variable. |
| All scaffolds must be printed using same printer | Not met | The minimum (30%) and maximum (20%) porosity samples, that were mass produced, were printed using separate printers from the medium (25%) porosity sample. |
| The force applied to the bone scaffold in the experiment must be consistent | Not met | Weight was gradually added to the cross-section however was not consistent when adding because human weights are difficult to control having constantly shifting centres of gravity. |

# D(iii) Identify improvements to the design

Monday, May 3, 2021 8:16 AM

**IMPROVEMENT 1 (needs more work on**

| Improvement |
|---|
| Using TCM Series motorised test stands in place of water weights. |
| Details |
| Throughout each trial, inconsistent mass is added each interval. For example, the second trial of the 25% infill model had the 71kg applied to its cross-section in one go making the scaffold instantly shatter and the result being significantly higher than the other trials. By using a motorised machine, all tests can be identical because the weight applied to scaffold will be equally consistent per trial. This improvement enhances the accuracy of the results. This improvement will affect the household item-restricting success criteria. |

Which of the following did you consider for this improvement (tick all that apply):

| Time | Material | Design Specifications | Client Needs | Limitations |
|---|---|---|---|---|
|  | x | x |  | x |

**IMPROVEMENT 2:**

| Improvement |
|---|
| The experiment's dependent variable being stress vs strain. |
| Details |
| The maximum mass dependent variable means only the maximum capacity of the scaffold can be determined. Whereas, stress vs strain provides information on both how much mass is needed to fracture the scaffold and how the scaffold deforms before fracture. This information could have been useful to inform the client on the safety of the scaffold. This change will affect the variables of the experiment and the methodology but the format including the independent variable will be mostly similar to prior to change. Therefore the independent variable specification won't be affected. |

Which of the following did you consider for this improvement (tick all that apply):

| Time | Material | Design Specifications | Client Needs | Limitations |
|---|---|---|---|---|
|  |  | x | x |  |

**IMPROVEMENT 3:**

| Improvement |
|---|
| Conducting more trials. |
| Details |
| Although the minimum trials are 6, more trials could have been done to improve the accuracy of the descriptive statistics to its actual value. This concept was discussed in C(iv) Justifying changes to the creation plan. This improvement will affect the experiment 30 minute time limit specification, and will alter the creation plan and material list. |

Which of the following did you consider for this improvement (tick all that apply):

| Time | Material | Design Specifications | Client Needs | Limitations |
|---|---|---|---|---|
| x | x | x |  | x |